208

An Ecosystem Approach to Water Quality Standards

Report of the Technical Committee
on Water Quality Standards
Technical Report No. 1
December 1, 1977

November 30, 1977

Mrs. Jacqueline Parnell, Project Manager
208 Areawide Waste Treatment
Management Plan
State Department of Health
1250 Punchbowl Street
Honolulu, Hawaii 96813

Dear Mrs. Parnell:

RE: Transmittal, Report of the 208 Technical Committee on Water Quality Standards

Attached is the final report of the 208 Technical Committee on Water Quality Standards. This document represents the culmination of the Committee's efforts to establish a set of manageable and technically sound water quality standards for the State of Hawaii.

The standards contained in this volume are based upon the premise that our aquatic ecosystems are precious resources which must be protected; a philosophy promulgated by the "non-degradation" policies set forth in the 1972 Amendments to the Federal Water Pollution Control Act (P.L. 92-500).

Also included in this document are: background information, detailed ecosystem descriptions, technical justifications of the standards and references used in setting the standards.

We thank you for the opportunity to participate in Hawaii's 208 planning efforts.

Sincerely,

James E. Maragos

James E. Maragos, Chairman
208 Technical Committee on
Water Quality Standards

"AN ECOSYSTEM APPROACH TO WATER QUALITY STANDARDS"

Report of the Technical Committee on
Water Quality Standards

The preparation of this report was financed in part through a 208 Areawide Waste Treatment Management Plan Grant from the U.S. Environmental Protection Agency.

HAWAII, DEPARTMENT OF HEALTH
State of Hawaii
December 1, 1977

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PREFACE

How The Proposed Standards Are Organized And Presented

This document presents the proposed water quality standards and necessary supporting documents to provide the justification, explanation, rationale and approach utilized by the Department of Health's Technical Committee on Water Quality Standards during evolution and development of the standards.

The standards are organized around a classification of state waters summarized on page ix and explained and defined in more detail in Appendix 1. Based upon this classification system, there are three groups of water quality standards described in Chapters 1, 2, and 3. Chapter 1 concerns the standards for the inland or fresh waters of the State, Chapter 2 concerns the standards for the marine or coastal waters of the State, and Chapter 3 concerns the standards for the marine bottom environments within the State.

Presentation of the standards follows the format described below for each water category in the classification system:

1) a concise definition of the water category
2) the properties and numerical values of the standards for the category
3) the allowable water uses and their geographic locations for the category.

This format is repeated over and over again for each water category.

Only the standards themselves are presented in Chapters 1-3. For those interested in determining the rationale and justification for the standards, it is necessary to consult Appendices 2, 3, and 4 which are the "justification" reports for the inland, marine water, and marine bottom standards respectively. The justification reports will also provide committee recommendations on the frequency and type of measurements for water quality field monitoring, but since the committee is still working on these recommendations, they are necessarily incomplete at this time.

Appendices 5-9 provide technical information and references for some of the more detailed or complex standards. Appendix 5 presents criteria for minimum stream flow standards; Appendices 6 and 7 present U. S. Environmental Protection Agency recommended standards for toxic materials in receiving waters, a necessary inclusion because of the absence of relevant information for Hawaii; and Appendices 8 and 9 present expanded definitions of the proposed water use levels for inland and marine waters respectively.

INTRODUCTION

Why Change The Existing Water Quality Standards For The State Of Hawaii?

There are both institutional and technical reasons for the changes. The Section 208 Study Plan provides the answers from the first perspective. From a purely technical standpoint, the existing standards are inadequate, inaccurate, and need substantial revision to protect the many diverse and important aquatic environments in Hawaii.

How Will The Standards Protect Water Quality In Hawaii?

Effective water quality management is possible if:

1) appropriate, objective, and legally supportable standards are adopted;
2) an organized and adequate field program to monitor water quality conditions in the State is established to determine when and whether water quality standards are in violation; and
3) the adopted standards and water uses are enforced.

The standards should be intentionally set at values or levels which, if exceeded, will reflect ecological, aesthetic and other types of water quality problems. The monitoring program will serve to "flag" water quality violations and problems when they occur and to determine the cause of such problems. The water quality management agency will then decide whether to take action to correct the problem or to exempt it because of other overriding considerations. Thus, to be effective, the standards will need to be technically correct in order that "real" water quality problems are identified during field monitoring.

How Is Water Quality Measured?

The "quality" of the water is ascertained by measuring its properties, such as temperature, oxygen, fish density, coral abundance, etc. The properties, if properly selected, serve as indicators of when the water quality is acceptable or unacceptable. The water quality standards represent, in effect, the minimum acceptable water quality based upon ecological, aesthetic, or other criteria. To determine whether the water quality at a particular location is meeting the requirements identified in the standards, field measurements of water quality properties are taken at the site and then compared to the allowable levels established in the standards for the waters at the site.

Water quality management can also utilize the allowable water uses designated for each type (and location) of water in the State. The responsibility to insure that the actual water uses conform to those adopted rests with the water quality management agency.

How Were The Proposed Standards Developed?

Hawaii's waters are of many types and varieties such as reefs, wetlands, estuaries, streams, lakes, pools, ponds, bogs, springs, etc., and differ substantially from those found elsewhere in the country. For one, Hawaii's tropical island environment mandates greater emphasis on marine water quality. Based upon the approach utilized by the committee, the first step in setting standards was to recognize the natural differences and variety of the waters of the State so that appropriate standards and uses could be stablished for each. This was accomplished by classifying the state's waters (Table 1, Appendix 1); these waters are separated into inland and marine divisions and the marine division is further separated into marine water column and marine bottom subdivisions. The latter was necessary because it is essential that the bottom standards serve as long-term indicators and because of the fact that the quality of the overlying marine waters frequently does not correspond or correlate to that of the marine bottom environment immediately below. Also, marine bottom communities serve as long-term and sensitive indicators of water quality compared to water column communities.

The classification system developed is based upon actual (not idealized) ecosystems as we find them when not degraded by waste disposal and other forms of pollution. Correspondingly, the proposed standards are set to maintain these ecosystems in a natural, relatively undisturbed state.

Appropriate standards and uses were then assigned for each water category and in each case, the combination of standards and allowable uses are uniquely different. The standards (Chapters 1-3) were developed after a thorough and careful review of water quality data, with emphasis placed on water quality information collected in Hawaii, unless such data were lacking. The water properties or parameters selected for the standards (such as temperature, oxygen, etc.) were judged to serve as good indicators of the presence or absence of water quality problems, depending upon their value at particular locations.

The numbers for the standards were then set at some intermediate value or level after comparing water quality measurements from "polluted" areas to those of "pristine" areas. For situations where sufficient data were lacking, best professional judgment was exercised. In setting the standards, this judgment was based upon experience in the real world (Hawaii) and not something extracted from a textbook or manual. In any case, the cause-and-effect processes occurring on land or in the water leading to the water quality problems were clearly delineated and understood prior to the decision to select certain water properties and their corresponding levels as standards. The standards are, therefore, less "stringent" than conditions expected in pristine or unpolluted waters but more stringent than water quality conditions in polluted or disturbed waters. The exact details and rationale for the standards are presented in Appendices 2-4.

Finally, it is important to note that the proposed standards here focus on ecological and aesthetic criteria. Another committee, the Health Effects Committee, is considering standards from a public health standpoint and these standards will be added and evaluated separately at a later date.

How Are The Standards Expressed?

Water quality can be extremely variable depending upon season, tides, rainfall, waves, and other natural factors, and as a consequence, it is necessary to utilize three different numerical expressions for the standards:

1) The geometric mean of all measurements should not exceed one certain value (the lowest);
2) 10% of the measurements should not exceed a second (and intermediate) value; and
3) no individual measurement should exceed a third (and usually highest) value at any time.

Expressing the standards in this way will enable them to be more accurate and not be "violated" by infrequent acts of nature such as storms, floods, etc. This, in turn, will allow water quality management to focus on problems attributed to human activities rather than waste effort and resources on "false alarms".

How Were The Allowable Uses Developed For Each Category?

The committee listed and analyzed all the possible uses of waters in Hawaii and determined that all could be naturally categorized into one of four water use levels. Beginning with the "highest" use level and working downwards, these are:

I. PRISTINE - PRESERVATION
II. LIMITED CONSUMPTIVE
III. EXPLOITIVE CONSUMPTIVE, and
IV. CONSTRUCT - ALTER

The general definitions for each of these levels are presented in Appendices 9-10 with slightly different definitions for inland waters compared to marine waters.

The appropriate and known geographical examples or locations of each water category were then assigned to one or more of these four use levels, depending upon a variety of factors and the water quality requirements unique to each water category. The factors included (but were not limited to): the value of each area for recreation, fish and wildlife propagation, critical habitat for endangered species, unique ecological or natural resources, fishing, water supply, flood control, economic development, sewage disposal, public health, aesthetics, education, scientific value, agriculture, industry, etc. Important considerations or qualifications on the placement of certain areas under certain water use levels is also presented in the standards (Chapters 1-3) within the use sections for each water category.

How Do The Proposed Standards Differ From The Existing Standards?

There are several major differences. For one, the existing standards are based upon a simple classification (2 inland and 3 coastal categories) developed from use criteria rather than based upon the natural characteristics or features of the waters themselves. As a consequence, the existing standards do not account for the natural variability of the aquatic environment and allow the lumping of dissimilar waters under the same use categories and water quality standards. Also the classification system lacks sufficient details and categories.

The existing standards were promulgated at a time when water quality research and information was not as extensive as what exists today, and emphasis was primarily directed towards public health considerations. The proposed standards will compensate for these shortcomings and will place heavy emphasis on ecological criteria.

The existing standards are only expressed simply as numbers not to be exceeded, not taking into consideration the extreme variability of water quality conditions that can be caused by acts of nature. Also, many of the standards are ambiguously defined and difficult to enforce. The proposed standards rectify these problems by utilizing three numerical expressions for the standards and by being more explicitly defined.

Finally, the existing standards lack many details on permissible uses, and many areas are not adequately treated on an individual basis. As mentioned before, many dissimilar waters are grouped within the same standards and uses. The allowable water uses of the proposed standards provide considerably more rationale and details for the designations because a broader range of uses and the variability of the waters themselves are taken into account. As a consequence, the proposed standards consider the use tolerances and requirements unique to each type of water in Hawaii.

Acknowledgements

A list of the committee members and other contributors to the proposed standards is presented in the next section. Outside of Department of Health personnel, none of the committee members received financial compensation from "208" or the Department of Health for their efforts. As a consequence, the management of the many governmental agencies are acknowledged for allowing their scientists and engineers to devote considerable work time in this "public interest" endeavor and to thank the personnel themselves for their interest and efforts, some beyond normal job responsibilities. Committee members from private environmental and engineering firms in Hawaii are thanked for volunteering all of their services, and committee members from the University of Hawaii system are thanked for devoting considerable time and interest to the project.

The committee committed many hours - substantially in excess of anyone's initial expectations - towards compilation of the proposed standards during the past 1½ years. Obviously, it was more than just a job to these people - considerable personal dedication, concern and "aloha" for Hawaii's aquatic environment were certainly motivating factors. These people deserve special commendation for their accomplishments.

Last but not least, the Committee acknowledges the constant inspiration and fine support by the Department of Health, particularly Dr. James Kumagai, Ms. Jacqueline Parnell, Mr. Melvin Koizumi and Ms. Dawn Yaatame.

WATER QUALITY STANDARDS
TECHNICAL COMMITTEE MEMBERS

Name	Background/Function
Eugene Akazawa Department of Health	Pollution investigation and enforcement
Paul Bartram Pacific Urban Studies and Planning Program/Coastal Zone Management	Pollutant transfer processes. Marine bottom water quality standards
Paul Bienfang Oceanic Institute	Marine water quality/microbiology
S. Allen Cattell Environmental Consultants, Inc.	Plankton/marine chemistry/water column classification, parameters and standards
Evan C. Evans Naval Undersea Center	Infauna/soft bottom communities/classification of state waters
John Ford UH-Cooperative Fishery Research Unit	Wetlands/estuaries/streams. Inland water quality standards
Jed Hirota Hawaii Institute of Marine Biology	Marine water column/plankton
Jeff Hunt Windward Community College	Marine bottom communities/benthic algae
E. Alison Kay UH-General Science	Marine bottom communities/micromollusks
George Krasnick Environmental Consultants, Inc.	Marine water column, classification and parameters
Hans Krock M & E Pacific, Inc.	Water quality/numerical expression of standards
Peter Kroopnick UH-Oceanography	Marine chemistry
Ed Laws Hawaii Institute of Marine Biology	Marine productivity/review of national water quality objectives, parameters and recommendations

Lionel Low M & E Pacific, Inc.	Water quality/numerical expression of standards
John Maciolek UH-Zoology/U. S. Fish and Wildlife Service	Wetlands/streams/estuaries, classification of inland waters
James Maragos U. S. Army Corps of Engineers	Committee Chairman/coral reefs
Jacquelin Miller UH-Environmental Center	Water quality data storage and retrieval
Margo Stahl Hawaii Institute of Marine Biology	Fishes/classification of marine bottom waters
Hiroshi Yamauchi UH-Agricultural Economics	Water resources/uses
Richard Yasunaga Department of Health	Pollution technical review
Johnson Yee U. S. Geological Survey	Water quality/inland water quality standards
Reginald Young UH-Water Resources Research Center	Water quality/uses

Other Contributors

The following individuals also contributed information or ideas during the development of these standards: William Magruder, UH Department of Botany (marine bottom communities and algae); Tom Clarke, UH Institute of Marine Biology (deep sea fisheries); J. Frisbee Campbell, UH Institute of Geophysics (marine geology); Ralph Moberly, UH Institute of Geophysics (marine geology); Paul Struhsaker (fisheries); Robert Johannes, UH Institute of Marine Biology (marine biology); Richard Grigg, UH Institute of Marine Biology (deep benthos); Stephen Lau, UH Water Resources Research Center (water quality); Eric Guinther, Environmental Consultants, Inc. (bottom communities); Ron Nolan, Ocean Research Consulting and Analysis (marine fishes); and Gordon Dugan, UH Water Resources Research Center (water quality).

SUMMARY CLASSIFICATION OF STATE WATERS

(Refer to Appendix 1 for complete details on the classification)

Inland Waters	
Water Types	**Ecological Subtypes**
A. Freshwater	1. Streams 2. Ditches and flumes 3. Springs and seeps 4. Natural lakes 5. Reservoirs 6. Elevated wetlands 7. Low wetlands
B. Mixohaline and Saline	8. Coastal wetlands 9. Estuaries 10. Anchialine pools

Marine Waters	
Water Types	**Bottom Subtypes**
C. Embayments 1. Wet 2. Dry 3. Seasonally wet	11. Lava rock shorelines 12. Sand beaches 13. Solution benches 14. Marine pools and protected coves 15. Artificial basins 16. Nearshore reef flats 17. Offshore reef flats 18. Wave-exposed reef communities 19. Protected coral communities 20. Soft bottom communities
D. Open Coast 1. Wet 2. Dry 3. Seasonally wet	
E. Transition	21. Deep benthos
F. Open Ocean	

Chapter 1

INLAND WATER QUALITY STANDARDS

STREAMS

Description

Perennial Streams - Freshwaters flowing downhill in definite natural channels, portions of which may be modified. Flowing water is present year-round but volume varies from low flow (from groundwater sources) in dry season to high flow (augmented by surface runoff) in wet season. Streams may be continuous, with perennial flow from headwaters to ocean, or interrupted, having perennial flow only in part of channel (usually upstream), with seasonal discharge to ocean.

Intermittent Streams - Freshwaters flowing downhill in definite natural channels only during part of the year (wet season). All of flow is from surface runoff. Sections of channels may be modified.

*Proposed Water Quality Standards

Parameter	Geometric mean not to exceed the given value	Not to exceed the given value more than 10% of the time	Not to exceed the given value at any time
Total Kjeldahl Nitrogen (mg N/1)	0.18 (dry season) 0.25 (wet season)	0.38 (dry season) 0.52 (wet season)	0.60 (dry season) 0.80 (wet season)
Nitrate + Nitrite [mg $(NO_3 + NO_2)$-N/1]	0.03 0.07	0.09 0.18	0.17 0.30
Total Phosphorus (mg P/1)	0.03 0.05	0.06 0.10	0.08 0.15
Total Non-Filtrable Residue (mg/1)	10 20	30 50	55 80
Turbidity (Nephelometric Turbidity Units)	2.0 5.0	5.5 15.0	10.0 25.0
Fecal Coliform (Colonies per 100 ml)	110 150	800 1400	2800 5000

pH - Shall not deviate more than 0.5 units from natural conditions. Not less than 5.5 nor more than 8.0.

Dissolved Oxygen (% saturation) - Not less than 80% saturation.

Temperature (°C) - Shall not vary more than 1°C from natural conditions.

Specific Conductance (micromhos/cm) - Not more than 300 micromhos/cm.

Toxic Substances - Shall not exceed concentrations recommended by the Environmental Protection Agency for freshwaters (see Appendix 6).

Minimum Stream Flow - See Appendix 5.

Proposed Bottom Standards

Physical/Chemical Environment

Sudden deposits of flood-borne terrigenous sediment on hard substrata shall not exceed a thickness of 5 mm (.20 inch) for longer than 24 hours following a heavy rainstorm for hard substrata.

Sudden deposits of flood-borne terrigenous sediment on soft substrata shall not exceed a thickness of 10mm (.40 inch) for longer than 24 hours following a heavy rainstorm for soft substrata.

Oxidation-reduction potential (E_H) in the top 10 cm (4 inches) shall not be less than +100 mv in soft substrata in pool sections of streams.

No more than 50% of the grain size distribution of sediment should be smaller than 0.2mm (.008 inch) in diameter in soft substrata in pool sections of streams.

Biological Structure

Repeat surveys of permanent benchmark stations and comparative "before and after" surveys shall not indicate significant reduction in relative abundance of native species compared to baseline levels.

<u>Allowable Uses</u> (see Appendix 8 for Use Classification and Descriptions)

I.a. Pristine-Preservation: Public access allowed.

Kauai - Awaawapuhi
Hanakoa
Honopu
Kalalau
Milolii
Nualolo
Waiahuakua

Oahu - None

Molokai - Pelekunu (Lanipuni, Kawaipaka, Kawainui, Kawailena)
Pulena

Maui - Waiohinu
Hahalawe

Hawaii - Waimanu (Kakaauki, Waiilikahi)

II.b. Pristine-Preservation: Public access restricted.

Kauai - Currently designated restricted watersheds

Oahu - Currently designated restricted watersheds

Molokai - Currently designated restricted watersheds

Maui - Wailua
Puaaluu
Currently designated restricted watersheds

Hawaii - Currently designated restricted watersheds

II. Limited Consumptive

Kauai - Hanalei
Koula
Kalihiwai
Kilauea
Limahuli
Lumahai
Manoa
Poomau
Wainiha
Lawai
Hanakapiai
Waialae
Koaie

Oahu - Manoa (Palolo)
Maunawili
Nuuanu
Waihee
Punaluu
Waiahole
Waikane
Waimea
Kaluanui
Kaneohe (Kamooalii)
Kahana (Kawa)
Heeia
Opaeula
Kahaluu (Ahuimanu)

Molokai - Halawa
Wailau
Kawainui
Waialeia
Waialua
Waiahookalo
Kalawao

Maui - Makamakaole
Kahakuloa
Iao
Waiehu
Waihee
Waikapu
Ukumehame
Alelele
Hanawi
Haepuena
Nonomanu
Hoolawa
Kailua
Kapaula
Kopiliulia
Nailiilihaele
Puohokamaa
E. Wailuaiki
W. Wailuaiki
Wailuanui
Waiohue
Paakea
Palikea (Pipiwai)
Piinaau (Palaukulu)

Hawaii - Honokane Iki
Honokane Nui
Waihilau
Hiilawe
Waima
Koiawe
Waipio
Alakahi
Kawainui
Pololu
Waikoloa
Kaiailakilahi
Kapehu
Maulua
Pohakupuka
Waikaumalo
Manue
Opea
Umauma
Hakalau
Kolekole
Paheehee
Honomu
Kapehu
Waiaaina
Kawainui
Hanawi
Kapue
Pahoehoe
Honoui
Maile
Pukihae
Waiau
Wailuku
Kaiwiki
Kaieie

III. Exploitive Consumptive

Kauai - Anahola
Anini
Aakukui
Hanamaulu
Huleia
Hanapepe
Kapaa
Konohiki
Moloaa
Nawiliwili
Wahiawa
Waimea
Wailua
Waiole
Waipa
Waipao
Niumalu

Oahu - Halawa
Hakipuu
Anahula
Makiki
Waiawa (Waimano)
Waikele (Kipapa)
Waimalu
Paumalu
Helemano
Malaekahana
Kahawainui
Ulehawa
Makaleha
Kalauao
Kaupuni
Kiikii (Poamoho, Kaukonaiwa)
Mailiilii
Oio

Molokai - Waikolu
Pilipililau
Kapuhi
Others not listed

Maui - Honokohau
Honokowai
Honolua
Kahoma (Kahana)
Kauaula
Launiupoko
Waikamoi
Olowalu
Punalau
Waiaaka
Waiele
Waipio
Waiokamilo
Nuaailua
Ohia
Oopuola
Kalena
Koukoalie
Kukuiula

Hawaii - Other streams not listed in the previous three categories.

*NOTE: Establishment of additional water quality standards likely pending acquisition of baseline water quality monitoring data.

DITCHES AND FLUMES

Description

Freshwaters flowing downhill in channels that are entirely artificial. The source is generally stream diversions or reservoir out-flow.

*Proposed Water Quality Standards

Toxic Substances - Shall not exceed concentrations recommended by the Environmental Protection Agency for freshwaters (see Appendix 2).

Allowable Uses (see Appendix 8 for Use Classification and Descriptions)

I.b. Pristine-Preservation: Public access restricted

Designated domestic water supply transmission

III. Exploitive Consumptive

All areas not otherwise specified

*NOTE: Establishment of additional water quality standards likely pending acquisition of baseline water quality monitoring data.

SPRINGS AND SEEPS

Description

Small, perennial, relatively constant freshwater flows not in distinct channels (e.g., wet films or trickles over rock surface). Water emanating from elevated aquifers. Two subtypes: stream-associated, occurring in deeply cut valleys and contributing to stream flow and coastal, occurring on coastal escarpments and usually flowing into the ocean.

*Proposed Water Quality Standards

Toxic Substances - Shall not exceed concentrations recommended by the Environmental Protection Agency for freshwaters (see Appendix 6).

Allowable Uses (see Appendix 8 for Use Classification and Descriptions)

I.a. Pristine-Preservation: Public access allowed.

Designated Natural Area Reserves; areas not otherwise specified.

I.b. Pristine-Preservation: Public access restricted.

Designated restricted watershed areas; areas not otherwise specified.

II. Limited Consumptive

All areas within watersheds designated under this use category for streams.

III. Exploitive Consumptive

Only where water diversion will not seriously degrade habitat.

*NOTE: Establishment of additional water quality standards likely pending acquisition of baseline water quality monitoring data.

NATURAL LAKES

Description

Deep (greater than 6.6 feet, or 2 meters) standing water that is always fresh (salinity less than 0.5 $^{o}/oo$) in well-defined natural basins.

*Proposed Water Quality Standards

No discharges of substances or materials allowed which would modify ambient water quality conditions.

Allowable Uses (see Appendix 8 for Use Classification and Descriptions)

All four natural lakes (listed below) are designated Class I.a., Pristine-Preservation: Public access allowed.

Molokai - Meyer Lake

Maui - Waiele'ele Lake

Hawaii - Waiau Lake
Green Lake

*NOTE: Establishment of additional water quality standards likely pending acquisition of baseline water quality monitoring data.

RESERVOIRS

Description

Deep (greater than 6.6 feet, or 2 meters) standing water that is always fresh (salinity less than 0.5 $^o/oo$) in well-defined artificial basins.

*Proposed Water Quality Standards

Toxic Substances - Shall not exceed concentrations recommended by the Environmental Protection Agency for freshwaters (see Appendix 6).

Specific Conductance - Shall not vary more than 10% from natural conditions. Not more than 400 micromhos/cm.

pH - Not less than 6.0 and not more than 8.0.

Allowable Uses (see Appendix 8 for Use Classification and Definitions)

II. Limited Consumptive

Public recreation areas only

III. Exploitive Consumptive)
and/or) All areas not otherwise specified
IV. Construct/Alter)

*NOTE: Establishment of additional water quality standards likely pending acquisition of baseline water quality monitoring data.

ELEVATED WETLANDS

Description

Shallow (less than 3 feet, or approximately 1 meter) standing water that is always fresh (salinity less than 0.5 $^{o}/oo$) in more or less indistinct basins such as natural bogs, ponds, and marshes. Found in undisturbed areas, mainly remote uplands and forest reserves.

*Proposed Water Quality Standards

Toxic Substances - Shall not exceed concentrations recommended by the Environmental Protection Agency for freshwaters (see Appendix 6).

pH - Not less than 4.5 and not more than 7.0.

Allowable Uses (see Appendix 8 for Use Classification and Descriptions)

I.a. Pristine-Preservation: Public access allowed.

Critical habitat for rare, threatened, and endangered species; areas nominated as Natural Area Reserves.

Kauai - Alakai Swamp
Kanaele Bog
Maui - Kahakuloa
Hawaii - Kohala Bogs
Molokai - Hanalilolilo-Makolelau

I.b. Pristine-Preservation: Public access restricted.

Designated restricted watershed areas; all other areas not otherwise specified

II. Limited Consumptive

Established recreational fishing areas and areas of partially degraded habitat.

*NOTE: Establishment of additional water quality standards likely pending acquisition of baseline water quality monitoring data.

LOW WETLANDS

Description

Shallow (less than 6.6 feet, or 2 meters) standing water that is always fresh (salinity less than 0.5 $^{o}/oo$) in ponds and marshes. Found in lowland areas near coast or in valley termini modified by man. Origin may be natural or man-made.

*Proposed Water Quality Standards

Toxic Substances - Shall not exceed concentrations recommended by the Environmental Protection Agency for freshwaters (see Appendix 6).

Allowable Uses (See Appendix 8 for Use Classification and Descriptions)

I.a. Pristine-Preservation: Public access allowed

. Critical habitats for rare, threatened, and endangered species.

II. Limited Consumptive

All other areas not otherwise specified

*NOTE: Establishment of additional water quality standards likely pending acquisition of baseline water quality monitoring data.

COASTAL WETLANDS

Description

Natural or man-made ponds and marshes having variable salinity, basin limits, and permanence. Mainly adjoining coastline, but not surface-connected to ocean except in rare circumstances and usually without tidal fluctuations. Introduced biota, especially fishes.

*Proposed Water Quality Standards

Toxic Substances - Shall not exceed concentrations recommended by the Environmental Protection Agency for freshwaters (see Appendix 6).

Allowable Uses (see Appendix 8 for Use Classification and Descriptions)

I.a. Pristine-Preservation: Public access allowed

Critical habitats for rare, threatened, and endangered species.

I.b. Pristine-Preservation: Public access restricted

Laysan Atoll - lagoon
Molokai - Kauhako Lake

II. Limited Consumptive

All other areas not otherwise specified

*NOTE: Establishment of additional water quality standards likely pending acquisition of baseline water quality monitoring data.

ESTUARIES

Description

Characteristically mixohaline (salinity 0.5 to 30 $^{o}/oo$) standing waters in definite basins with continuous or seasonal surface connection to ocean that allows entry of euryhaline marine fauna. Further subdivided into natural estuaries that occur mainly at stream and river mouths, and developed estuaries that are artificial or strongly modified from natural state, such as dredged and revetted stream termini.

*Proposed Water Quality Standards

A. Applicable to all estuaries

Parameter	Geometric mean not to exceed the given value	Not to exceed the given value more than 10% of the time	Not to exceed the given value at any time
Total Kjeldahl Nitrogen (ug N/l)	200	350	500
Ammonia (ug NH_4 - N/l)	6.0	10.0	20.0
Nitrate + Nitrite [ug $(NO_3 + NO_2)$-N/l]	8.0	25.0	35.0
Orthophosphate (ug PO_4 - P/l)	10.0	30.0	40.0
Total Phosphorus (ug P/l)	25.0	50.0	75.0
Light Extinction Coefficient (k)	0.40	0.80	1.0
Chlorophyll *a* (ug/l)	2.0	5.0	10.0
Turbidity (Nephelometric Turbidity Units)	1.50	2.0	5.0
Non-Filtrable Residue (mg/l)	35.0	45.0	50.0

pH - Not less than 7.0 and not greater than 8.6.

Dissolved Oxygen (% saturation) - Not less than 75% saturation.

S-09-270

Temperature (°C) - Shall not vary more than 1°C from ambient conditions.

Salinity (°/oo) - Shall not vary more than 10% from ambient conditions.

Toxic Substances - Shall not exceed concentrations recommended by the Environmental Protection Agency for marine waters (see Appendix 7).

B. Applicable only to Pearl Harbor estuary

Parameter	Geometric mean not to exceed the given value	Not to exceed the given value more than 10% of the time	Not to exceed the given value at any time
Total Kjeldahl Nitrogen (ug N/l)	300	550	750
Ammonia (ug NH_4 - N/l)	10	20	30
Nitrate + Nitrite [ug (NO_3 + NO_2)-N/l]	15	40	70
Orthophosphate (ug PO_4 - P/l)	20	48	90
Total Phosphorus (ug P/l)	60	130	200
Light Extinction Coefficient (k)	0.8	1.6	2.5
Chlorophyll *a* (ug/l)	3.5	10	20
Turbidity (Nephelometric Turbidity Units)	4.0	8	15
Non-Filtrable Residue (mg/l)	50	75	100

Allowable Uses (see Appendix 8 for Use Classification and Descriptions)

I.a. Pristine-Preservation: Public access allowed

All other areas not specified in other use categories

II. Limited Consumptive

All designated estuarine sanctuaries

Hawaii - Waimanu
Kauai - Lumahai
Kilauea

III. Exploitive Consumptive

Only areas where habitat is partially degraded

Hawaii - Waipio

IV. Construct/Alter

Only areas where habitat is severely altered

Oahu - Pearl Harbor

*NOTE: Establishment of additional water quality standards likely pending acquisition of baseline water quality monitoring data.

ANCHIALINE POOLS

Description

Natural exposures of standing waters near coastline in recent lavas (rarely, in fossil reefs) and having tidal fluctuations. Mostly small shallow pools of low salinity (1 to 10 $^{o}/oo$) with distinctive biota (no fishes) not surface connected to ocean except in rare circumstances.

Proposed Water Quality Standards

No discharge of substances or materials allowed which would modify ambient water quality conditions.

Allowable Uses (see Appendix 8 for Use Classification and Descriptions)

I.a. Pristine-Preservation: Public access allowed

All critical habitats for rare, threatened, and endangered species; all Natural Area Reserves.

II. Limited Consumptive

All other areas not otherwise specified.

Chapter 2

MARINE WATER QUALITY STANDARDS

EMBAYMENTS

Description

An embayment is defined as having a total bay water volume to bay entrance cross sectional area of 700:1 or greater. Embayments are bounded by headlands which restrict exchange of water with the open ocean. As a consequence, the residence time of water in embayments is increased over that for waters in open coastal areas, allowing for the accumulation of land drainage materials which influence water quality and marine ecosystems.

This category has been split into three divisions which were determined by the amount of freshwater inflow from the land.

"Wet" embayments are exposed to freshwater inflow from the land year-round. The average freshwater inflow approaches 1% of the water body volume per day.

"Dry" embayments are not exposed to significant freshwater inflow from the land, receiving less than 1% average freshwater inflow per water body volume per day.

"Seasonally wet" embayments are exposed to freshwater inflow from the land only at certain times of the year. At those times, the average freshwater inflow approaches 1% of the water body volume per day.

Proposed Water Quality Standards ("Wet" Embayments)

Parameter	Geometric mean not to exceed the given value	Not to exceed the given value more than 10% of the time	Not to exceed the given value at any time
Total Kjeldahl Nitrogen (ug N/l)	200	350	500
Ammonia (ug NH_4 - N/l)	6.0	13.0	20.0
Nitrate + Nitrite [ug $(NO_3 + NO_2)$-N/l]	8.0	20.0	35.0
Orthophosphate (ug PO_4 - P/l)	10.0	25.0	40.0
Total Phosphorus (ug P/l)	25.0	50.0	75.0

Parameter	Geometric mean not to exceed the given value	Not to exceed the given value more than 10% of the time	Not to exceed the given value at any time
Light Extinction Coefficient (k)	0.40	0.80	1.2
Chlorophyll *a* (ug/1)	1.5	4.5	8.5
Turbidity (Nephelometric Turbidity Units)	1.50	2.0	5.0
Non-Filtrable Residue (mg/1)	25.0	40.0	50.0

pH - Shall not deviate more than 0.5 units from a value of 8.1 units.

Dissolved Oxygen (% saturation) - Not less than 75% saturation.

Temperature (°C) - Shall not vary more than 1°C from ambient conditions.

Salinity (°/oo) - Shall not vary more than 10% from ambient conditions.

Toxic Substances - Shall not exceed concentrations recommended by the Environmental Protection Agency for marine waters (see Appendix 7).

Proposed Water Quality Standards ("Dry" Embayments)

Parameter	Geometric mean not to exceed the given value	Not to exceed the given value more than 10% of the time	Not to exceed the given value at any time
Total Kjeldahl Nitrogen (ug N/1)	110	180	250
Ammonia (ug NH_4 - N/1)	2.0	5.0	9.0
Nitrate + Nitrite [ug (NO_3 + NO_2)-N/1]	3.5	10.0	20.0
Orthophosphate (ug PO_4 - P/1)	5.0	8.0	13.0
Total Phosphorus (ug P/1)	16.0	30.0	45.0

Parameter	Geometric mean not to exceed the given value	Not to exceed the given value more than 10% of the time	Not to exceed the given value at any time
Light Extinction Coefficient (k)	0.15	0.35	0.60
Chlorophyll *a* (ug/l)	0.50	1.50	3.0
Turbidity (Nephelometric Turbidity Units)	0.40	1.00	1.50
Non-Filtrable Residue (mg/l)	15.0	25.0	35.0

pH - Shall not deviate more than 0.5 units from a value of 8.1 units.

Dissolved Oxygen (% saturation) - Not less than 75% saturation.

Temperature (^{o}C) - Shall not deviate more than $1^{o}C$ from ambient conditions.

Salinity ($^{o}/oo$) - Shall not vary more than 10% from ambient conditions.

Toxic Substances - Shall not exceed concentrations recommended by the Environmental Protection Agency for marine waters (see Appendix 7).

Proposed Water Quality Standards ("Seasonally Wet" Embayments)

Parameter	Geometric mean not to exceed the given value	Not to exceed the given value more than 10% of the time	Not to exceed the given value at any time
Total Kjeldahl Nitrogen (ug N/l)	150 (dry season) 200 (wet season)	250 (dry season) 350 (wet season)	350 (dry season) 500 (wet season)
Ammonia (ug NH_4 - N/l)	3.5 6.0	8.5 13.0	15.0 20.0
Nitrate + Nitrite [ug (NO_3 + NO_2)-N/l]	5.0 8.0	14.0 20.0	25.0 35.0
Orthophosphate (ug PO_4 - P/l)	7.0 10.0	12.0 25.0	17.0 40.0

Parameter	Geometric mean not to exceed the given value	Not to exceed the given value more than 10% of the time	Not to exceed the given value at any time
Total Phosphorus (ug P/1)	20.0 25.0	40.0 50.0	60.0 75.0
Light Extinction Coefficient (k)	0.15 0.40	0.35 0.80	0.60 1.20
Chlorophyll a (ug/1)	0.50 1.5	1.50 4.5	3.0 8.5
Turbidity (Nephelometric Turbidity Units)	0.40 1.50	1.00 2.00	1.50 5.00
Non-Filtrable Residue (mg/1)	15.0 25.0	25.0 40.0	35.0 50.0

pH - Shall not deviate more than 0.5 units from a value of 8.1 units.

Dissolved Oxygen (% saturation) - Not less than 75% saturation.

Temperature (°C) - Shall not deviate more than 1°C from ambient conditions.

Salinity (°/oo) - Shall not deviate more than 10% from ambient conditions.

Toxic Substances - Shall not exceed concentrations recommended by the Environmental Protection Agency for marine waters (see Appendix 7).

Allowable Uses: Applicable to All Types of Embayments (See Appendix 9 for Use Classification and Descriptions)

I. Pristine-Preservation

Oahu - Hanauma Bay

II. Limited Consumptive

All other areas not otherwise specified.

III. Exploitive Consumptive

Kauai - Nawiliwili Boat Harbor
Port Allen
Kikiaola Harbor
Kukuiula Harbor

Oahu - Honolulu Harbor and Keehi Lagoon
Kewalo Basin
Barber's Point Harbor (proposed)
Haleiwa Harbor
Waianae Harbor
Ala Wai Harbor

Maui - Kahului Harbor
Lahaina Harbor
Maalaea Harbor

Hawaii - Hilo Harbor
Kawaihae Harbors
Honokohau Harbor

Lanai - Manele Harbor

OPEN COASTAL WATERS

Description

Open coastal waters begin at the shoreline and extend seaward to the 100 fathom (600 feet, or 183 meters) depth contour. This category includes small bays with good water movement which do not qualify as embayments. These waters are still under terrigenous influence and support plankton populations larger than the open ocean but smaller than embayments.

This category was split into three divisions which were determined by the amount of freshwater input received from the land.

"Wet" open coastal waters are exposed to significant freshwater inflow from the land (greater than an average of 3.0×10^6 gallons per mile of coastline per day).

"Dry" open coastal waters are not exposed to significant freshwater inflow from the land (less than an average of 0.5×10^6 gallons per mile of coastline per day).

"Seasonally wet" open coastal waters are exposed to significant freshwater inflow from the land on a seasonal basis (greater than an average of 3.0×10^6 gallons per mile of coastline during "wet" season and less than an average of 0.5×10^6 gallons per mile of coastline per day during the dry season).

Proposed Water Quality Standards ("Wet" Open Coastal Waters)

Parameter	Geometric mean not to exceed the given value	Not to exceed the given value more than 10% of the time	Not to exceed the given value at any time
Total Kjeldahl Nitrogen (ug N/l)	150	250	350
Ammonia (ug NH_4 - N/l)	3.5	8.5	15.0
Nitrate + Nitrite [ug (NO_3 + NO_2)-N/l]	5.0	14.0	25.0
Orthophosphate (ug PO_4 - P/l)	7.0	12.0	17.0
Total Phosphorus (ug P/l)	20.0	40.0	60.0

Parameter	Geometric mean not to exceed the given value	Not to exceed the given value more than 10% of the time	Not to exceed the given value at any time
Light Extinction Coefficient (k)	0.20	0.50	0.85
Chlorophyll <u>a</u> (ug/1)	0.30	0.90	1.75
Turbidity (Nephelometric Turbidity Units)	0.50	1.25	2.0
Non-Filtrable Residue (mg/1)	20.0	30.0	40.0

pH - Shall not deviate more than 0.5 units from a value of 8.1 units.

Dissolved Oxygen (% saturation) - Not less than 75% saturation.

Temperature (^{o}C) - Shall not deviate more than $1^{o}C$ from ambient conditions.

Salinity ($^{o}/oo$) - Shall not deviate more than 10% from ambient conditions.

Toxic Substances - Shall not exceed concentrations recommended by the Environmental Protection Agency for marine waters (see Appendix 7).

<u>Proposed Water Quality Standards</u> ("Dry" Open Coastal Waters)

Parameter	Geometric mean not to exceed the given value	Not to exceed the given value more than 10% of the time	Not to exceed the given value at any time
Total Kjeldahl Nitrogen (ug N/1)	110	180	250
Ammonia (ug NH_4 - N/1)	2.0	5.0	9.0
Nitrate + Nitrite [ug (NO_3 + NO_2)-N/1]	3.5	10.0	20.0
Orthophosphate (ug PO_4 - P/1)	5.0	9.0	13.0
Total Phosphorus (ug P/1)	16.0	30.0	45.0

Parameter	Geometric mean not to exceed the given value	Not to exceed the given value more than 10% of the time	Not to exceed the given value at any time
Light Extinction Coefficient (k)	0.10	0.30	0.55
Chlorophyll *a* (ug/1)	0.15	0.50	1.0
Turbidity (Nephelometric Turbidity Units)	0.20	0.50	1.0
Non-Filtrable Residue (mg/1)	10.00	15.00	20.0

pH - Shall not deviate more than 0.5 units from a value of 8.1 units.

Dissolved Oxygen (% saturation) - Not less than 75% saturation.

Temperature (°C) - Shall not deviate more than 1°C from ambient conditions.

Salinity (°/oo) - Shall not deviate more than 10% from ambient conditions.

Toxic Substances - Shall not exceed concentrations recommended by the Environmental Protection Agency for marine waters (see Appendix 7).

<u>Proposed Water Quality Standards</u> ("Seasonally Wet" Open Coastal Waters)

Parameter	Geometric mean not to exceed the given value	Not to exceed the given value more than 10% of the time	Not to exceed the given value at any time
Total Kjeldahl Nitrogen (ug N/1)	110 (dry season) 150 (wet season)	180 (dry season) 250 (wet season)	250 (dry season) 350 (wet season)
Ammonia (ug NH_4 - N/1)	2.0 3.5	5.0 8.5	9.0 15.0
Nitrate + Nitrite [ug (NO_3 + NO_2)-N/1]	3.5 5.0	10.0 14.0	20.0 25.0
Orthophosphate (ug PO_4 - P/1)	5.0 7.0	9.0 12.0	13.0 17.0

Parameter	Geometric mean not to exceed the given value	Not to exceed the given value more than 10% of the time	Not to exceed the given value at any time
Total Phosphorus (ug P/1)	16.0 20.0	30.0 40.0	45.0 60.0
Light Extinction Coefficient (k)	0.10 0.20	0.30 0.50	0.55 0.85
Chlorophyll <u>a</u> (ug/1)	0.15 0.30	0.50 0.90	1.0 1.75
Turbidity (Nephelometric Turbidity Units)	0.20 0.50	0.50 1.25	1.0 2.0
Non-Filtrable Residue (mg/1)	10.0 20.0	15.0 30.0	20.0 40.0

pH - Shall not deviate more than 0.5 units from a value of 8.1 units.

Dissolved Oxygen (% saturation) - Not less than 75% saturation.

Temperature (^{o}C) - Shall not deviate more than $1^{o}C$ from ambient conditions.

Salinity ($^{o}/oo$) - Shall not deviate more than 10% from ambient conditions.

Toxic Substances - Shall not exceed concentrations recommended by the Environmental Protection Agency for marine waters (see Appendix 7).

<u>Allowable Uses: Applicable to All Types of Open Coastal Waters</u> (see Appendix 9 for Use Classification and Descriptions)

II. Limited Consumptive

All other areas not otherwise specified.

III. Exploitive Consumptive (receiving water sites for acceptable existing and planned treated thermal and sewage discharges; by permit only).

Kauai - Wailua

Oahu - Sand Island
Honouliuli
Fort Kamehameha
Barbers Point
Waianae
Kahe
Sandy Beach
Mokapu

Maui - Paia
Lahaina

Hawaii - Hamakua Coast

TRANSITION WATERS

Description

There is no clear cut break between open coastal waters and oceanic waters. Therefore, there is a zone of transition - extending from the 100 fathom (600 feet, or 183 meters) depth contour to the 500 fathom (3000 feet, or 915 meters) depth contour - which is relatively free of terrestrial influence and whose plankton content is reduced from that of coastal waters.

Proposed Water Quality Standards

Parameter	Geometric mean not to exceed the given value	Not to exceed the given value more than 10% of the time	Not to exceed the given value at any time
Total Kjeldahl Nitrogen (ug N/1)	55.0	90.0	120.0
Ammonia (ug NH_4 - N/1)	1.5	3.0	4.5
Nitrate + Nitrite [ug (NO_3 + NO_2)-N/1]	2.0	3.5	5.0
Orthophosphate (ug PO_4 - P/1)	3.0	6.0	9.0
Total Phosphorus (ug P/1)	12.0	21.0	30.0
Light Extinction Coefficient (k)	0.05	0.085	0.12
Chlorophyll a (ug/1)	0.08	0.15	0.25
Turbidity (Nephelometric Turbidity Units)	0.05	0.15	0.30
Non-Filtrable Residue (mg/1)	5.0	10.0	15.0

pH - Shall not deviate more than 0.5 units from a value of 8.1 units.

Dissolved Oxygen (% saturation) - Not less than 75% saturation.

Temperature (^{o}C) - Shall not deviate more than $1^{o}C$ from ambient conditions.

Salinity ($^{o}/oo$) - Shall not deviate more than 10% from ambient conditions.

Toxic Substances - Shall not exceed concentrations recommended by the Environmental Protection Agency for marine waters (see Appendix 7).

<u>Allowable Uses</u> (See Appendix 9 for Use Classification and Descriptions)

II. Limited Consumptive)
and/or) both types of uses apply to all
III. Exploitive Consumptive) Transition waters

(Receiving water sites for acceptable existing and planned treated thermal and sewage discharges; Environmental Protection Agency designated deep ocean sites for disposal of dredged materials; by permit only.)

OCEANIC WATERS

Description

Open ocean waters extend seaward from the 500 fathom (3000 feet, or 915 meters) contour. They are very clear, low in nutrients, and plankton content.

Proposed Water Qaulity Standards

Parameter	Geometric mean not to exceed the given value	Not to exceed the given value more than 10% of the time	Not to exceed the given value at any time
Total Kjeldahl Nitrogen (ug N/1)	50.0	80.0	100
Ammonia (ug NH_4 - N/1)	1.0	1.75	2.5
Nitrate + Nitrite [ug (NO_3 + NO_2)-N/1]	1.5	2.5	3.5
Orthophosphate (ug PO_4 - P/1)	1.0	3.0	5.0
Total Phosphorus (ug P/1)	10.0	18.0	25.0
Light Extinction Coefficient (k)	0.04	0.07	0.10
Chlorophyll a (ug/1)	0.06	0.12	0.20
Turbidity (Nephelometric Turbidity Units)	0.03	0.10	0.20
Non-Filtrable Residue (mg/1)	3.0	6.0	9.0

pH - Shall not deviate more than 0.5 units from a value of 8.1 units.

Dissolved Oxygen (% saturation) - Not less than 75% saturation.

Temperature (°C) - Shall not deviate more than 1°C from ambient conditions.

Salinity (°/oo) - Shall not deviate more than 10% from ambient conditions.

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Toxic Substances - Shall not exceed concentrations recommended by the Environmental Protection Agency for marine waters (see Appendix 7).

<u>Allowable Uses</u> (See Appendix 9 for Use Classification and Descriptions)

II. Limited Consumptive	)	
and/or	)	both types of uses apply to all Oceanic
III. Exploitive Consumptive	)	waters

(Receiving water sites for acceptable existing and planned treated thermal and sewage discharges; Environmental Protection Agency designated deep ocean sites for disposal of dredged materials; by permit only.)

Chapter 3

WATER QUALITY STANDARDS FOR MARINE BOTTOM TYPES

LAVA ROCK SHORELINES

Description

Sea cliffs and other vertical rock faces, horizontal basalt and basaltic tuff benches and boulder beaches formed by rocks falling from above or deposited by storm waves. Associated algae and animals are adapted to the harsh physical environment and distinctly zoned according to the degree of wave exposure.

Proposed Bottom Standards

Physical/Chemical Environment

Sudden deposits of flood-borne terrigenous sediment shall not exceed a thickness of 5 mm (.20 inch) for longer than 24 hours following a heavy rainstorm.

Accumulations of pesticides/heavy metals in the tissues of indicator organisms collected from this bottom type inside embayments should not exceed safe levels for human consumers, as indicated by recommendations from the Environmental Protection Agency (see Appendix 8 for recommended levels and indicator species).

Biological Structure

Repeat surveys of permanent benchmark stations representing this bottom type and comparative "before and after" surveys shall not indicate significant changes in vegetative-type algal cover or significant changes in calcareous-type algal cover from baseline levels or significant changes in bottom invertebrate abundance.

Allowable Uses (see Appendix 9 for Use Classification and Descriptions)

I. Pristine Preservation: Rocky shorelines of pinnacles and rocks (but not atolls) in the leeward Hawaiian Islands which are part of a U.S. Fish and Wildlife refuge.

II. Limited Consumptive

All but man-made shorelines.

IV. Construct/Alter

All man-made shorelines.

SAND BEACHES

Description

Shorelines composed of: 1) the weathered calcareous remains of foraminiferans, mollusks, coralline algae, reef-building corals and echinoderms (white sand); 2) the weathered remains of basaltic tuff (olivine); or 3) the weathered remains of basaltic lava (black sand). Associated animals are largely burrowers and are related to particle grain size, slope and color of the beach.

Proposed Bottom Standards

Physical/Chemical Environment

Sudden deposits of flood-borne terrigenous sediment shall not exceed a thickness of 10 mm (.40 inch) for longer than 24 hours following a heavy rainstorm.

Oxidation-reduction potential (E_H) in the uppermost 10 cm (4 inches) of sediment shall not be less than +100 mv.

No more than 50% of the grain size distribution of sediment shall be smaller than .2 mm (.008 inch) in diameter.

<u>Allowable Uses</u> (see Appendix 9 for Use Classification and Descriptions)

I. Pristine-Preservation

All beaches on the Northwest Hawaiian Islands

II. Limited Consumptive

All

Those activities which interfere with turtle migration and nesting are not allowed on the following beaches:

Molokai - Halawa Beach

Hawaii - Orr's Beach
Punaluu Beach

SOLUTION BENCHES

Description

Sea level platforms developed on upraised reef or consolidated sand by the erosive action of waves and rain. Solution benches are distinguished by a thick algal turf and conspicuous zonation of algae and animals.

Proposed Bottom Standards

Physical/Chemical Environment

Sudden deposits of flood-borne sediment shall not exceed thickness of 5 mm (.20 inch) for longer than 24 hours following a heavy rainstorm.

Biological Structure

Repeat surveys of permanent benchmark stations representing this bottom type and comparative "before and after" surveys shall not indicate significant changes from baseline levels in vegetative-type algal cover (especially species associated with poor water quality) or significant changes in calcareous-type algal cover or significant changes in bench invertebrate abundance.

Allowable Uses (see Appendix 9 for Use Classification and Descriptions)

II. Limited Consumptive

Kauai - Near Hanapepe salt ponds
Milolii
Nualolo
Makaha
Mahualepu
Kuhio Beach Park

Oahu - Diamond Head
Manana Island
Makapu
Laie
Kahuku
Mokuleia
Makua
Makaha
Maile
Lualualei
Barbers Point

Maui - Kihei
Papaula Point

MARINE POOLS AND PROTECTED COVES

Description

Marine pools form in depression on sea-level basalt outcrops and solution benches and also behind large boulders fronting the sea. Pools farthest from the ocean have harsher environments and less frequent renewal of water and support fewer animals. Those closest to the ocean are frequently renewed with water, are essentially marine and support more diverse flora and fauna.

Protected coves are removed from heavy wave action or surge.

Proposed Bottom Standards

Physical/Chemical Environment

In marine pools and coves with sand bottoms, oxidation-reduction potential (E_H) in the uppermost 10 cm (4 inches) of sediment shall not be less than +100 mv.

In marine pools and coves with sand bottoms, no more than 50% of the grain size distribution of the sediment shall be smaller than .2 mm (.008 inch) diameter.

Sudden deposits of flood-borne terrigenous sediment shall not exceed the following thicknesses for longer than 24 hours following a heavy rainstorm:

No thicker than 5 mm (.20 inch) on hard substrata (other than living corals)

No thicker than 10 mm (.40 inch) on soft substrata

Biological Structure

Repeat surveys of permanent benchmark stations representing this bottom type and comparative "before and after" surveys shall not indicate: 1) significant changes from baseline levels in vegetative-type algae cover (especially by species associated with poor water quality), 2) significant changes in calcareous-type algal cover and 3) significant decreases in tide pool fishes.

Allowable Uses (see Appendix 9 for Use Classification and Descriptions)

I. Pristine-Preservation: Existing or proposed reserves or preserves.

Hawaii - Honaunau
Kiholo

II. Limited Consumptive

Kauai	- Kealia Mohaulepu Hanamaulu	Poipu Puolo Point	
Oahu	- Diamond Head Halona Blowhole to Makapuu Mokuleia		Kaena Point Makua Punaluu
Molokai	- Cape Halawa Kalaupapa South Coast		
Maui	- Hana Keanae Napili	Puu Olai to Cape Hanamanioa Kipahulu	
Hawaii	- Kalapana Pohakuloa Kopalaoa	Haenokalele Kapoho King's Landing	Hilo Leleiwe Point Wailua Bay

ARTIFICIAL BASINS

Description

Dredged channels and boat basins, quarried harbors and harbor-associated submerged structures. Many organisms can attach to the vertical structures but the soft, shifting sediment bottoms of harbors can only be colonized by a few hardy or transient species.

Proposed Bottom Standards

Physical/Chemical Environment

Oxidation-reduction potential (E_H) in the uppermost 10 cm (4 inches) of sediment shall not be less than -100 mv.

Accumulations of pesticides/heavy metals in the tissues of indicator organisms collected from this bottom type shall not exceed safe levels for human consumers, as indicated by recommendations from the Environmental Protection Agency (see Appendix 8 for recommended levels and indicator species).

Allowable Uses (see Appendix 9 for Use Classification and Description

IV. Construct/Alter

*A. Shallow draft recreational harbors

Kauai - Nawiliwili Small Boat Harbor
Kukuiula Harbor
Kikiaola Harbor

Oahu - Heeia Kea Harbor
Kaneohe Bay Marina
Kaneohe Marine Corps Air Station
Kaneohe Yacht Club
Hawaii Kai Marina (Kuapa Pond)
Pokai Bay
Waianae Harbor
Ala Wai Harbor
Keehi Harbor
La Mariana
Pearl Harbor (recreational harbor)
Haleiwa Harbor

Molokai - Kalaupapa anchorage
Kaunakakai Small Boat Harbor
Haleolono Small Boat Harbor

Lanai - Manele Harbor
Kaumalapau Harbor

Hawaii	- Wailoa Harbor Mahukona Harbor Keauhou Harbor	Kailua-Kona Harbor Honokohau Harbor Kawaihae Small Boat Harbor
Maui	- Maalaea Harbor Lahaina Harbor Hana Harbor	

*B. Deep draft commercial harbors

Kauai	- Nawiliwili Harbor	Port Allen Harbor
Oahu	- Honolulu Harbor Pearl Harbor (except West Loch) Barbers Point Harbor	Kewalo Basin
Maui	- Kahului Harbor	
Hawaii	- Kuhio Bay (Hilo Harbor) Kawaihae Deep Draft Harbor	
Molokai	- Kaunakakai Barge Harbor	

*Note: Because of significant differences in the quality of waters in shallow recreation boat harbors compared to deeper commercial harbors, it may be necessary to differentiate between the two with respect to water quality standards and allowable uses when sufficient information becomes available to determine them.

NEARSHORE REEF FLATS

Description

Shallow platforms of reef rock, rubble and sand extending from the shoreline. Smaller, younger flats project out as semi-circular aprons while older, larger flats form wide continuous platforms. Dominant organisms are bottom-dwelling algae. Associated animals are mollusks, echinoderms, worms, crustaceans (many living beneath the surface) and reef-building corals.

Proposed Bottom Standards

Physical/Chemical Environment

Oxidation-reduction potential (E_H) in the uppermost 10 cm (4 inches) of sediment portions of this bottom type shall not be less than +100 mv.

No more than 50% of the grain size distribution of sediment portions of this bottom type shall be smaller than 0.2 mm (.008 inch) diameter.

Accumulations of pesticides/heavy metals in the tissues of indicator organisms collected from this bottom type inside embayments shall not exceed safe levels for human consumers, as indicated by recommendations from the Environmental Protection Agency (see Appendix 8 for recommended levels and indicator species).

Sudden deposits of flood-borne terrigenous sediment shall not exceed the following thicknesses for longer than 24 hours following a heavy rainstorm:

No thicker than 2 mm (.08 inch) on living coral surfaces

No thicker than 5 mm (.2 inch) on other hard substrata

No thicker than 10 mm (.4 inch) on soft substrata

Biological Structure

Repeat surveys at permanent benchmark stations representing this bottom type and comparative "before and after" surveys shall not indicate: 1) significant changes in vegetative-type algal cover (especially by species associated with poor water quality) or significant changes in calcareous-type algal cover, 2) significant decreases in coral cover, especially by branching species sensitive to water quality change and 3) significant increases in the proportion of bottom invertebrates (excluding corals) whose feeding habits are associated with poor water quality.

Allowable Uses (see Appendix 9 for Use Classification and Descriptions)

I. Pristine-Preservation: Areas proposed or designated as preserves or reserves. Small scale non-degrading fishing activities allowed except where more restrictive controls on fishing (or collecting) specified by other agencies.

Kauai - Nualolokai
Hanalei

Oahu - Hanauma Bay

Molokai - Western Kalaupapa
Southeast Molokai reef (specific sites to be specified later)
Honomuni Harbor

Lanai - Northeast Lanai reef

Maui - Honolua

Hawaii - Puako

II. Limited Consumptive

All others not otherwise indicated

III. Exploitive Consumptive: Existing or planned harbors located within nearshore reef flats showing significantly degraded habitats and only where feasible alternatives are lacking; by permit only (future harbors).

Oahu - Keehi Harbor, Ala Moana Reef, Honolulu Harbor, Heeia Harbor, Kaneohe Yacht Club, Ala Wai Harbor, Haleiwa Harbor, Maunalua Bay, Pearl Harbor

Molokai - Kaunakakai Harbors
Haleolono Harbor
Palaau

Lanai - Manele

Maui - Lahaina Harbor
Kahului Harbor

Hawaii - Blonde Reef (Hilo Harbor)
Kawaihae Small Boat Harbor

OFFSHORE REEF FLATS

Definition

Shallow, submerged platforms of reef rock and sand between depths of 0 to 3 meters (0 to 10 feet) which are separated from the shoreline of high volcanic islands by lagoons or ocean expanses. Dominant organisms are bottom-dwelling algae. Biological composition is extremely variable. There are three types: patch, barrier and atoll reef flats; quite different from one another structurally. The presence of heavier wave action, water more oceanic in character and the relative absence of terrigenous influences distinguish offshore reef flats from nearshore reef flats.

Proposed Bottom Standards

Physical/Chemical Environment

Oxidation-reduction potential (E_H) in the uppermost 10 cm (4 inches) of sediment portions of this bottom type shall not be less than +100 mv.

No more than 50% of the grain size distribution of sediment portions of this botton type shall be smaller than .2 mm (.008 inch) in diameter.

Sudden deposits of flood-borne terrigenous sediment shall not exceed the following thicknesses for longer than 24 hours following a heavy rainstorm:

No thicker than 2 mm (.08 inch) on living coral surfaces

No thicker than 5 mm (.2 inch) on other hard substrata

No thicker than 10 mm (.4 inch) on soft substrata

Biological Structure

Repeat surveys at permanent benchmark stations representing this bottom type and comparative "before and after" surveys shall not indicate: 1) significant changes in vegetative-type algal cover (especially by species associated with poor water quality) or significant changes in calcareous-type algal cover, 2) significant decreases in coral cover (especially by branching species sensitive to water quality changes), 3) significant increases in the proportion of bottom invertebrates (excluding corals) whose feeding habits are associated with poor water quality and 4) significant decreases in reef fish abundance.

Allowable Uses (see Appendix 9 for Use Classification and Descriptions)

I. Pristine-Preservation: Areas proposed or designated as refuges, reserves, preserves; small-scale, non-degrading fishing allowed except where more restrictive controls on fishing (or collecting) specified by other agencies

Kure Atoll
Midway Islands
Pearl and Hermes Reef
Lisianski Atoll
Laysan Island
Maro Reef
Franch Frigate Shoals

Oahu - Moku o loe (Coconut Island, Kaneohe Bay)

II. Limited Consumptive

Oahu - Kapapa Barrier Reef
Kaneohe Patch Reefs (Kaneohe Bay)

WAVE EXPOSED REEF COMMUNITIES

Description

Wave exposed reef communities (with scattered sand channels and patches) found at depths up to 40 meters (131 feet) along coasts subjected to continuous or heavy wave action and surge. Further subdivided into a shallow zone (up to 10 meters or 32 feet) with heavy wave action and a deep zone (10 to 40 meters or 32 to 131 feet) with lower wave action. Dominated biologically by benthic algae. Reef-building corals and echinoderms are also conspicuous.

Proposed Bottom Standards

Physical/Chemical Environment

Oxidation-reduction potential (E_H) in the uppermost 10 cm (4 inches) of sand portions of this bottom type shall not be less than +100 mv.

No more than 50% of the grain size distribution of sand portions of this bottom type shall not be smaller than .2 mm (.008 inch) in diameter.

Sudden deposits of flood-borne terrigenous sediment shall not exceed the following thicknesses for longer than 24 hours following a heavy rainstorm:

No thicker than 2 mm (.08 inch) on living coral surfaces

No thicker than 5 mm (.2 inch) on other hard substrata

No thicker than 10 mm (.4 inch) on soft substrata

Biological Structure

Repeat surveys at permanent benchmark stations representing this bottom type and comparative "before and after" surveys shall not indicate: 1) significant changes in vegetative-type algal cover (especially by species associated with poor water quality) or significant changes in calcareous-type algal cover, 2) significant decreases in coral cover (especially by branching species sensitive to water quality changes), 3) significant increases in the proportion of bottom invertebrates (excluding corals) whose feeding habits are associated with poor water quality and 4) significant decreases in reef fish abundance.

<u>Allowable Uses</u> (see Appendix 9 for Use Classification and Descriptions)

I. Pristine-Preservation: Existing and proposed preserves or reserves and historic submerged lava flows; small-scale, non-degrading fishing allowed except where more restrictive controls on fishing (and collecting) specified by other agencies.

Kauai - Ke'e Beach
Poipu Beach
Kipukai

Lehua Island (off Niihau)

Niihau

Oahu - Sharks Cove (Pupukea)
Moku Manu Islands
Outer Hanauma Bay
Waimea Bay
Kawela Bay
Kahana Bay

Molokai - Moanui
Waikolu - Kalawao
Halawa Bay

Maui - Hana Bay
Makuleia Bay

Molokini Island

Hawaii - Koaie Cove
1823 Lava Flow (Punaluu)
1840 Lava Flow (North Puna)
1868 Lava Flow (South Point)
1887 Lava Flow (South Point)
1955 Lava Flow (South Point)
1960 Lava Flow (Kapoho)
1969 Lava Flow (Apua Point)
1970 Lava Flow (Apua Point)
1971 Lava Flow (Apua Point)
1972 Lava Flow (Apua Point)
1973 Lava Flow (Apua Point)

II. Limited Consumptive

All other wave exposed reef communities not otherwise indicated

PROTECTED CORAL COMMUNITIES

Description

Hard bottom communities (with scattered sand channels and patches) dominated by living coral thickets, mounds or platforms. Mostly found at depths of 10 to 30 meters (32 to 96 feet) along protected leeward coasts or in shallower water (up to sea level) in sheltered lagoons behind atoll or barrier reefs and in the calm reaches of bays or coves.

Proposed Bottom Standards

Physical/Chemical Environment

Oxidation-reduction potential (E_H) in the uppermost 10 cm (4 inches) of sand portions of this bottom type shall not be less than +100 mv.

No more than 50% of the grain size distribution of sand portions of this bottom type shall be smaller than .2 mm (.008 inch) in diameter.

Sudden deposits of flood-borne terrigenous sediment shall not exceed the following thicknesses for longer than 24 hours following a heavy rainstorm:

No thicker than 2 mm (.08 inch) of living coral surfaces

No thicker than 5 mm (.2 inch) on other hard substrata

No thicker than 10 mm (.4 inch) on soft substrata

Biological Structure

Repeat surveys at permanent benchmark stations representing this bottom type and comparative "before and after" surveys shall not indicate· 1) significant changes in vegetative-type algal cover (especially by species associated with poor water quality) or significant changes in calcareous-type algal cover, 2) significant decreases in coral cover (especially by branching species sensitive to water quality changes), 3) bottom invertebrates (excluding corals) whose feeding habits are associated with poor water quality and 4) significant decreases in reef fish abundance.

Allowable Uses (see Appendix 9 for Use Classification and Descriptions)

I. Pristine-Preservation: Historic submerged lava flows; existing and proposed refuges, preserves and reserves; small scale, non-degrading fishing allowed except where more restrictive controls on fishing (and collecting) specified by other agencies.

Kure Atoll Lagoon
Midway Lagoon
Pearl and Hermes Lagoon
Lisianski Lagoon
Maro Reef Lagoon
French Frigate Shoals Lagoon

Kauai - Hoai Cove

Oahu - Hanauma Bay
Moku o loe (Coconut Island, Kaneohe Bay)
Kahe

Molokai - Southeast Molokai
Kalaupapa
Honomuni Harbor

Lanai - Manele
Hulopoe

Maui - Honolua
Ahihi-La Perouse (including 1790 (?) Lava Flow at Cape Kinau)

Molokini Island

Hawaii - Puako
Honaunau
Kealakekua
Kiholo
Anaehoomalu
Hapuna
Kahaluu Bay
Keaweula
Milolii Bay to Keawaiki
Kailua-Kaiwi (Kona)
Onomea Bay
1801 Lava Flow (Keahole Or Kiholo)
1950 Lava Flow (South Kona)
1859 Lava Flow (Kiholo)
1919 Lava Flow (Milolii)
1926 Lava Flow (Milolii)

SOFT BOTTOM COMMUNITIES

Description

Poorly described and "patchy" communities, mostly of burrowing organisms, living in deposits at depths between 2 to 40 meters (6 to 130 feet). The particle size of sediment, depth below sea level, degree of water movement and associated sediment turnover dictate the composition of animals which rework the bottom with burrows, trails, tracks, ripples, hummocks and depressions.

Proposed Bottom Standards

Physical/Chemical Environment

Oxidation-reduction potential (E_H) in the uppermost 10 cm (4 inches) of sediment should not be less than -100 mv.

Allowable Uses (see Appendix 9 for Use Classification and Descriptions)

II. Limited Consumptive

All other areas not otherwise specified.

III. Exploitive Consumptive) environmentally suitable sand mining
and/or) deposits; by permit only.
IV. Construct/Alter)

DEEP BENTHOS

Description

Poorly described but extensive ocean bottom below 40 meters (130 feet), a depth that is reached at relatively short distances from the shoreline. Below this depth, reef-building corals do not thrive, water movement is greatly reduced and the deeper forms of animal life begin to appear. Several commercially valuable species of precious corals, crustaceans and demersal fish are associated with this bottom type.

Proposed Bottom Standards

Very little is known about this type of marine community at this time. No standards were assigned to it in terms of physical, chemical and biological parameters.

Allowable Uses (see Appendix 9 for Use Classification and Descriptions)

I. Pristine-Preservation

All precious coral beds are designated in this category except those areas where permits are given to harvest corals for commercial use.

APPENDICES

Appendix 1

CLASSIFICATION OF STATE WATERS: DEFINITIONS AND LOCATIONS

Proposed Classification of Hawaiian Waters

This classification of Hawaiian waters is part of Hawaii's on-going Areawide Waste Treatment Management Studv authorized by Section 208 of the Federal Water Pollution Control Act Amendments of 1972.

One of the objectives of a committee formed to recommend technical revisions to the state's water quality standards is to establish a more comprehensive water classification system. This classification system is to be based upon ecological and other natural criteria which reflect the variety, distribution and abundance of aquatic systems of relevance to water quality management.

The aquatic classes described in this document are thoroughly defined and mapped in order to clarify differences between classes and to improve operational use for field monitoring studies. Hopefully, this organization of Hawaii's waters will aid in maintaining the quality of these unique aquatic systems.

HAWAIIAN INLAND WATERS .

Introduction

The Hawaiian Archipelago has a great variety of waters of cultural and ecological significance as a result of its diverse topography, geology, and climate. The initial critical objective of the Technical Committee on Water Quality Standards has been to classify and inventory these diverse waters according to ecological concepts. A first logical step was to differentiate between two primary types, marine and inland waters. This presentation concerns the latter group, inland waters, which comprise all surface waters that are not directly part of the marine ecosystem complex. Inland waters range from isolated high-altitude fresh waters to saline or brackish coastal waters, such as estuaries, that are connected to the ocean.

The ecosystem concept includes consideration of both living and non-living elements. In this classification, the non-living components (physiochemical features, spatial extent) are referred to as the environment; all living organisms of a system are its biota, further divided into communities and species of flora and fauna. Although micro-organisms are an integral part of an ecosystem, descriptive emphasis is placed on the better-known macrobiota, particularly the more obvious aquatic animals. Habitat here refers to the ecosystem requirements of a given species which usually overlap broadly with those of other species in a community. Habitat, therefore, is not a spatially exclusive component of an ecosystem.

Other elements employed in defining and describing inland waters include origins of the environment (natural or man-made) and of the biota (native or introduced). Most natural environments can be distinguished by native inhabitants, but the great diversity, wide distribution, and frequent dominance of exotic species necessitates their inclusion in most ecosystem descriptions. Finally, an attempt has been made to complement this classification scheme with a preliminary inventory showing abundances and distributions of the various inland waters. (See Attachment 1)

The comprehensive classification scheme for Hawaiian inland waters is shown in Table 1. Its format is based on obvious environmental features. Initial division is made into the two primary water types, fresh (dissolved inorganic ions <0.5 0/00) and (saline dissolved inorganic ions >0.5 0/00). Twelve ecological subtypes are differentiated as flowing (lotic) or standing (lentic) waters, and by environmental origin, water depth, basin character, and relationship to the ocean. Flowing waters result from altitudinal gradients. Wetlands are shallow standing waters (usually <1 m deep). It should be noted that some subtypes, such as lakes, are isolated while others (e.g., stream, estuary) adjoin but can be separated by ecological boundaries. Each subtype is described environmentally and biologically in the following section.

This plan includes all surface waters of ecological significance regardless of their importance to present quality concepts. With continuing socio-economic growth, some water subtypes that now seem to be only ecological curiosities probably will become important in the State's water quality program.

In its present form, this classification is only ecological. To extend its function to water quality objectives, it will be necessary to further qualify or subdivide some of the ecological subtypes into use categories. Domestic water supply reservoirs, for example, eventually must be considered apart from reservoirs that function as aquatic recreation sites, canefield distribution basins, or receiving waters for mill effluents.

Distributions and relative abundances of eight ecological subtypes of inland waters are shown separately on maps of six of the Windward Hawaiian Islands (Kauai, Hawaii, Maui, Molokai, Niihau, and Oahu). Most ecological subtypes are shown as general locations rather than individual ecosystems. In three cases (Estuaries, Perennial Streams, and Natural Lakes), all known ecosystems in each category are depicted. Review of these data shows striking dissimilarities among islands with regard to their complements and distributions of inland water subtypes. Comparison of Hawaii and Kauai Islands, for example, shows that on Hawaii, streams are abundant but limited to windward Mauna Kea and Kohala slopes, reservoirs and estuaries are few, and many anchialine pools occur along much of the coastline; Kauai has no lakes or anchialine pools but reservoirs and estuaries abound, and streams are distributed broadly.

TABLE 1

CLASSIFICATION OF STATE WATERS

Inland Waters	
Water Types	Ecological Subtypes
A. Freshwater	1. Streams 2. Ditches and flumes 3. Springs and seeps 4. Natural lakes 5. Reservoirs (impoundments) 6. Elevated wetlands 7. Low wetlands
B. Mixohaline and Saline	8. Coastal wetlands 9. Estuaries 10. Anchialine pools

Marine Waters	
Water Types	Bottom Subtypes
C. Embayments 1. Wet 2. Dry 3. Seasonally wet	11. Lava rock shorelines 12. Sand beaches 13. Solution benches 14. Marine pools and protected coves 15. Artificial basins 16. Nearshore reef flats 17. Offshore reef flats 18. Wave-exposed reef communities 19. Protected coral communities 20. Soft bottom communities
D. Open Coast 1. Wet 2. Dry 3. Seasonally wet	
E. Transition	21. Deep benthos
F. Open Ocean	

Descriptive Highlights of Ecological Subtypes

Below are brief descriptions of prominent environmental features and characteristic biota together with relative abundances and distributions of the 10 ecological subtypes of inalnd waters. Considerable information is available for perennial streams and anchialine pools, but data are minimal for most other subtypes. This situation emphasizes the need for more survey and research on Hawaiian inland waters, especially those that are most important to water quality objectives. Until such studies are accomplished, the classification plan and especially the descriptive elements of this report should be considered provisional.

Descriptions of the biota include notation of distinguishing species or larger taxons (those that are found essentially only in the water subtype described), as well as representative taxons (those that usually occur in a given water subtype but may be found in others). Further notation on native and introduced biota is made where this factor is significant.

A. Freshwater Systems: 7 Ecological Subtypes.

1. Streams

a. Intermittent Streams

(1) Environmental Features. Seasonal surface drainages that persist for at least a few weeks per year in definite natural channels (gulches). Flowing water decreases in volume to slow-exchanging pools prior to desiccation.

(2) Biota. No perennial flora or fauna (e.g., fishes) present; biota either migratory or capable of withstanding prolonged desiccation. Distinguishing fauna includes ostracod crustaceans. Representative biota includes filamentous algae, oligochaete worms, ancylid limpets, aquatic beetles, and backswimmers (Hemiptera).

(3) Abundance and Distribution. Common on leeward slopes, all high islands, mostly at mid elevations (e.g., leeward Haleakala from Kaupo Gap clockwise to Makawao). Sometimes at high elevations (e.g., Pohakuloa Gulch, Mauna Kea).

b. Perennial Streams

(1) Environmental Features. Water flowing year-round in all or part of natural channels as a result of both surface runoff and groundwater influx. Headwaters originate below 2,000 m elevation. Most (59%) have continuous flow from headwaters to ocean but

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some smaller streams are naturally interrupted (i.e., perennial flow at higher elevations but discharging only seasonally to the ocean). Many naturally continuous streams are artificially interrupted by total diversion of normal flow. A definite altitudinal zonation of environmental character and biota (see below) exists.

(2) Biota. Distinguishing biota consists of native diadromous fauna (reside and spawn in stream but develop as larvae in ocean) that inhabit lower and mid reaches of stream. These are 3 species of o'opu (goby fishes: *Awaous stamineus*, *Lentipes concolor*, *Sicydium stimpsoni*), one opae (shrimp, *Atya bisulcata*), the hihiwai (snail, *Neritina granosa*), and a sponge (*Heteromyenia baileyi*). Representative native biota includes various filamentous algae and mosses, polychaete worm, thiarid and lymnaeid snails, insect larvae (especially Diptera such as midges and craneflies) and nymphs (Odonata: damselflies and dragonflies), palaemonid prawn, and euryhaline gobioid fishes. Representative introduced fauna includes caddisfly larvae, crayfish, Tahitian prawn, poeciliid fishes (guppy, swordtail), tilapia, Chinese catfish, loach, and various tadpoles. Native species are abundant in most streams on islands except Oahu where introduced species predominate. Characteristically, upper reaches of a typical stream are dominated by aquatic insects and lack fishes and crustaceans. Mid reaches have greatest abundances of endemic o'opu and atyid opae. Terminal reaches are characterized by the presence of euryhaline fishes and the native prawn.

(3) Abundance and Distribution. Current inventories list 365 perennial streams distributed among the five largest islands as follows: Kauai, 56; Hawaii, 124; Maui, 96; Molokai, 34; and Oahu, 55. Most streams occur on windward slopes, their distributional patterns are shown on the island maps. The State's largest stream by most criteria (length, drainage area, mean discharge) is the Wailuku River (Hawaii) but the Wailua River (Kauai) has the record maximum instantaneous discharge.

2. Ditches and Flumes

a. Environmental Features. Perennial water flowing in artificial channels mainly for the purpose of irrigation. Limited to elevations below 1,500 m. Efficient ditches have channel dimensions that vary little and are free of vegetational and rock obstructions. Source of water is primarily stream diversion. Affluent ditches carry water to reservoirs or user areas; effluent ditches drain reservoirs and use areas.

b. Biota. Ditches and flumes have had little ecological study. No distinguishing flora or fauna. Characteristic fauna includes aquatic insects and introduced fishes (e.g., tilapia, swordtails, Chinese catfish). Affluent ditches at higher altitudes generally are depauperate of aquatic biota probably as a result of shelter scarcity. Low altitude affluent ditches (e.g., taro culture supply) sometimes have abundant fauna including native prawn and o'opu as well as various exotic species. Some effluent ditches have low-quality water capable of supporting only the most tolerant organisms.

c. Abundance and Distribution. Most ditches and flumes are situated on Kauai, Maui, and Oahu. Actual numbers would be difficult to designate because many are constructed in an interconnected complex.

3. Springs and Seeps (Rheocrenes)

a. Environmental Features. Water flowing year-round for short distances over rock surfaces or in indistinct channels as a result of leakage from elevated aquifers. Water occurs mostly as thin films or trickles and sometimes is colored by flocculent ochre resulting from bacterial iron precipitation. Associated with windward coastal escarpments and deeply incised valleys (usually below 1,000 m. elevation) where they contribute to dry-season stream flow.

b. Biota. Distinguishing biota consists of lymnaeid snails of the genus *Erinna* and possibly certain species of mosses and damselfly nymphs. Representative biota includes gelatinous and filamentous algae, mosses, ferns, detritivorous leeches, other lymnaeid snails (*Pseudisidora* spp.), larvae of aquatic flies (Diptera), and damselfly nymphs (*Megalagrion* spp.).

c. Abundance and Distribution. Small ecosystems that individually number at least in the hundreds and probably in the thousands. Valley rheocrenes can be found along virtually all perennial stream drainages. Coastal rheocrenes occur where escarpments exist below upland areas of high rainfall particularly windward Kauai, Hawaii, E. Maui, and E. Molokai.

4. Natural Lakes

   a. Environmental Features. Standing freshwater deeper than 2 m in well-defined natural basins. No Hawaiian freshwater lake known to exceed 1 ha. in surface area. Watermass stratified vertically at least during part of year.

   b. Biota. No distinguishing biota known. Communities in each lake are different; aquatic insects are prominent but variable. No representative taxons with the possible exception of zooplankton or phytoplankton.

   c. Abundance and Distribution. Four lakes identified in the State: Waiau at 3,969 m, Mauna Kea; Green Lake at sea level near Kapoho (Puna District); Wai'ele'ele at 2,040 m, east Haleakala; and Meyer Lake at 617 m, central Molokai. See respective island maps for locations.

5. Reservoirs (Impoundments)

   a. Environmental Features. Standing freshwater deeper than 2 m in artificial basins. Substrata may be natural rock or soil or artificial (e.g., butyl rubber). Most are below 1,000 m elevation. Some reservoirs show seasonal thermal stratification. Many fluctuate in volume or depth with variations in water supply and use. Three kinds of reservoirs relative to water quality are: primary, for storage of high-quality stream water; secondary, contain lower quality water such as for redistribution; terminal effluent reservoirs are receiving waters for plant or mill discharge.

   b. Biota. No distinguishing native biota; reservoirs are not habitats for native fauna. Distinguishing introduced biota includes certain fishes such as largemouth bass, tucunare, and threadfin shad. Representative biota includes a wide range of exotic plants and animals: water lilies and other vascular aquatic plants, bryozoans, snails, crayfish, *Tilapia* spp., poeciliid fishes, etc.

   c. Abundance and Distribution. More than 400 reservoirs exist in the State. Most of them are on Kauai, northern Hawaii, Maui, and Oahu. See island maps for locations. Largest is Waita Reservoir, Kauai (104 ha surface area). Most impoundments serve to store and distribute irrigation water; others function in flood control, domestic water supply, aquatic recreation, and effluent storage.

6. Elevated Wetlands

   a. Environmental Features. Shallow (< 2m) standing waters on flat topography in high-rainfall upland areas. Mostly less than 1 m deep in irregular or indistinct natural basins or in small craters. Waters vary from circumneutral to strongly acid depending upon water exchange rate.

b. Biota. No distinguishing biota known. Representative biota essentially native: mosses, sedges, grasses, odonate nymphs (e.g., dragonflies), dytiscid beetles, dipterous insect larvae, zooplankton crustaceans.

c. Abundance and Distribution. Elevated wetlands are located mainly in remote uplands of forest reserves and parks. Many are small waterbodies best reckoned in abundance by sites rather than individual ecosystems. They occur on the five largest islands (see maps for locations). Typical sites are Alakai Swamp (Kauai), Mt. Kaala (Oahu), Eke Crater (Maui), and Kohala Crest (Hawaii).

7. Low Wetlands

a. Environmental Features. Shallow, standing, lowland, freshwaters in definite or indistinct basins that may be natural or artificial in origin. Maintained by stream, well, or ditch influent water or may be the exposed water table. This is a broad group of lentic waters that includes limnetic marshes, waterbird refuges, golf course ponds, taro fields, aquaculture ponds, etc.

b. Biota. No distinguishing biota except in special use sites such as taro (*Colocasia esculenta*) ponds. Strongly dominated by introduced biota that includes rushes (e.g., *Scirpus*), grasses (e.g., *Brachiaria*), floating aquatic plants (*Azolla*, *Eichornia*, *Pistia*, etc.), crayfish, snails, topminnows, tilapia, tadpoles, etc.

c. Abundance and Distribution. Low wetlands have not been inventoried but are known to occur on the five largest islands and possibly Niihau (see maps for prominent locations). Largest ecosystem of this subtype probably is Kawainui Marsh, Oahu.

B. Mixohaline and Saline Systems: 3 Ecological Subtypes.

8. Coastal Wetlands

a. Environmental Features. Shallow, sea-level ponds, pools or marshes with perennial, tidal, or seasonal water of variable salinity. Usually, these waters are mixohaline (0.5 to 30 $^o/oo$) but some become hyperhaline ($>$ 40 $^o/oo$) during dry seasons. Surface connection to ocean absent or rare. Origin may be natural or man-made. Most natural coastal wetlands have been modified significantly by man.

b. Biota. Distinguishing biota absent from most coastal wetlands but pickleweed (*Batis maritima*) characterizes salt marshes and certain primitive crustaceans (Conchostraca, Notostraca) are found only in playa "lakes". Representative biota mostly introduced species, includes mangrove, bullrush, sedges, snails (*Melania Assiminea*), water boatmen (*Trichocorixa*), tilapia, and sailfin molly (*Poecilia latipinna*). Water birds are common inhabitants.

c. Abundance and Distribution. Coastal wetlands include an assortment of waters that have not been inventoried. Examples include: salt marshes as at Campbell Industrial Park (Oahu); open ponds such as Kanaha and Kealia (Maui); man-made bird refuge ponds (West Loch, Oahu); playa "lakes" (Niihau). See maps for known locations.

9. Estuaries

a. Environmental Features. Deep mixohaline coastal waters in well-defined basins that have continuous or frequent surface connection to the ocean. Tidal fluctuations evident and mark inland extent of watermass. Mixohalinity never results from evaporation but is due to mixing of seawater and freshwater. Freshwater may be present but mixohaline water is dominant. Natural estuaries occur mainly at stream mouths but a few receive input from freshwater springs. Developed estuaries have basins that are man-made or strongly modified from a natural state. Most estuaries have strong vertical salinity stratification but some are stratified horizontally.

b. Biota. No distinguishing biota known. Representative biota is euryhaline. Native invertebrates include neritid snails (*Theodoxus*), barnacle (*Balanus*), shrimp (*Palaemon debilis*), prawn (*Macrobrachium grandimanus*), and crabs (*Thalamita, Metopograpsus*). Native fishes include ama'ama (*Mugil cephalus*), aholehole (*Kuhlia sandvicensis*), kaku (*Sphyraena barracuda*), and various o'opu (*Awaous genivittatus, Eleotris sandvicensis, Oxyurichtys lonchotus*). Representative introduced fauna includes Samoan crab, Marquesan mullet, and tilapia. Common waterbirds are coot, ducks, night heron.

c. Abundance and Distribution. Stream-mouth natural estuaries are most numerous on Kauai (13) with others on Oahu (2) and Molokai (1). Spring-fed natural estuaries occur on Hawaii near Hilo. Most developed estuaries are on Oahu; one example is the Ala Wai Canal. Estuary locations are shown on the island maps.

10. Anchialine Pools

a. Environmental Features. Exposures of mixohaline (1-30 0/00 groundwater located in coastal lavas and elevated fossil reefs and having no surface connection with the ocean but showing tidal fluctuation. Mixohalinity results from the dilution of intruding subterranean marine water with seaward-percolating fresh groundwater. Most anchialine pools have low salinity water (< 15 0/00) and may show vertical stratification. Morphology varies widely from pool and pond-like to water in fissures, fractures, lava tubes, and sinkholes. Substratum primarily rock but significant sediments occur in some pools.

b. Biota. Distinguishing flora includes widgeon grass (*Ruppia maritima*) in pools with sediments and crustose or mat-forming algal communities dominated by glue-green algae (*Scytonema*). Distinguishing fauna consists of several unusual shrimps such as opaeula (*Halocaridina rubra*) and an alpheid (*Metabetaeus lohena*). Other rare and blind shrimps also occur in certain pools. Representative biota includes sedges, succulents, chlorophytes, snails (*Melania*, *Assiminea*, *Theodoxus*), amphipods, and other shrimps (e.g., *Palaemon debilis*). Fishes are rare or absent. The presence of introduced fishes such as tilapia or poeciliids degrades this ecosystem to subtype 8 (Coastal Wetlands).

c. Abundance and Distribution. As an ecosystem, anchialine pools occur in various parts of the world, but for the United States, they apparently are unique to Hawaii. Actual numbers of anchialine pools cannot be determined with accuracy because many are very small and often groups of fifty or more water exposures occur in a limited area. They are located mostly on Hawaii near Kapoho (Puna) and along the leeward coast from Kawaihae to South Point. Other pond groups occur on East Maui. See map locations.

Attachment 1

Information Relating to Maps of Inland Water Ecosystems

1. Map entries of ecosystem types are positioned as accurately as possible relative to their actual locations.

2. Ecosystems entered on maps as follows:

   a. Streams - shown as water course lines

   b. Natural lakes - L

   c. Reservoirs (impoundments) - R

   d. Elevated wetlands - W

   e. Low wetlands (freshwater) - W_L

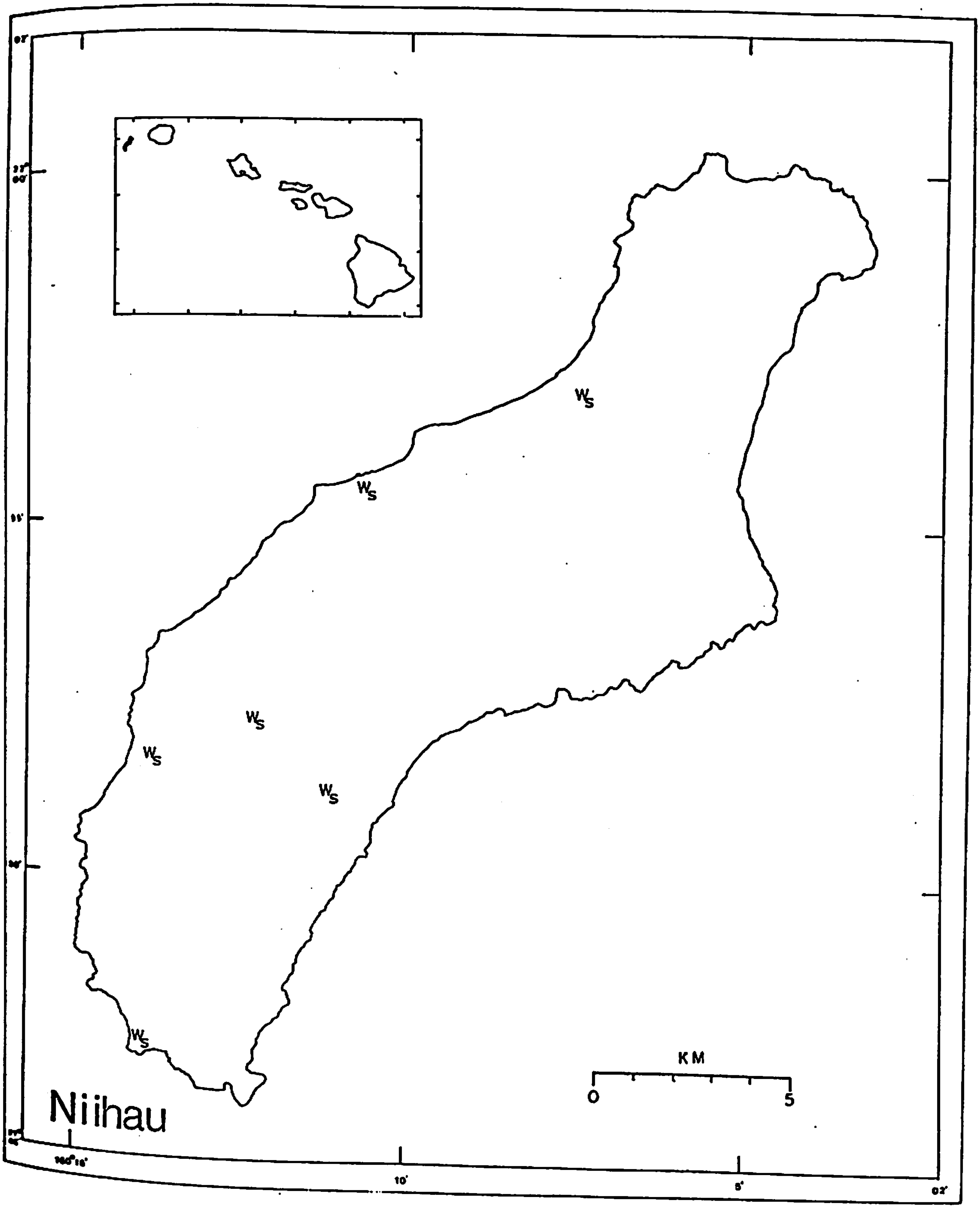
   f. Coastal wetlands (saline) - W_S

   g. Estuaries

      Natural - E
      Developed - E_D

   h. Anchialine pools - A

3. A plus sign (+) following code letter means more than one (ecosystem) at that location.



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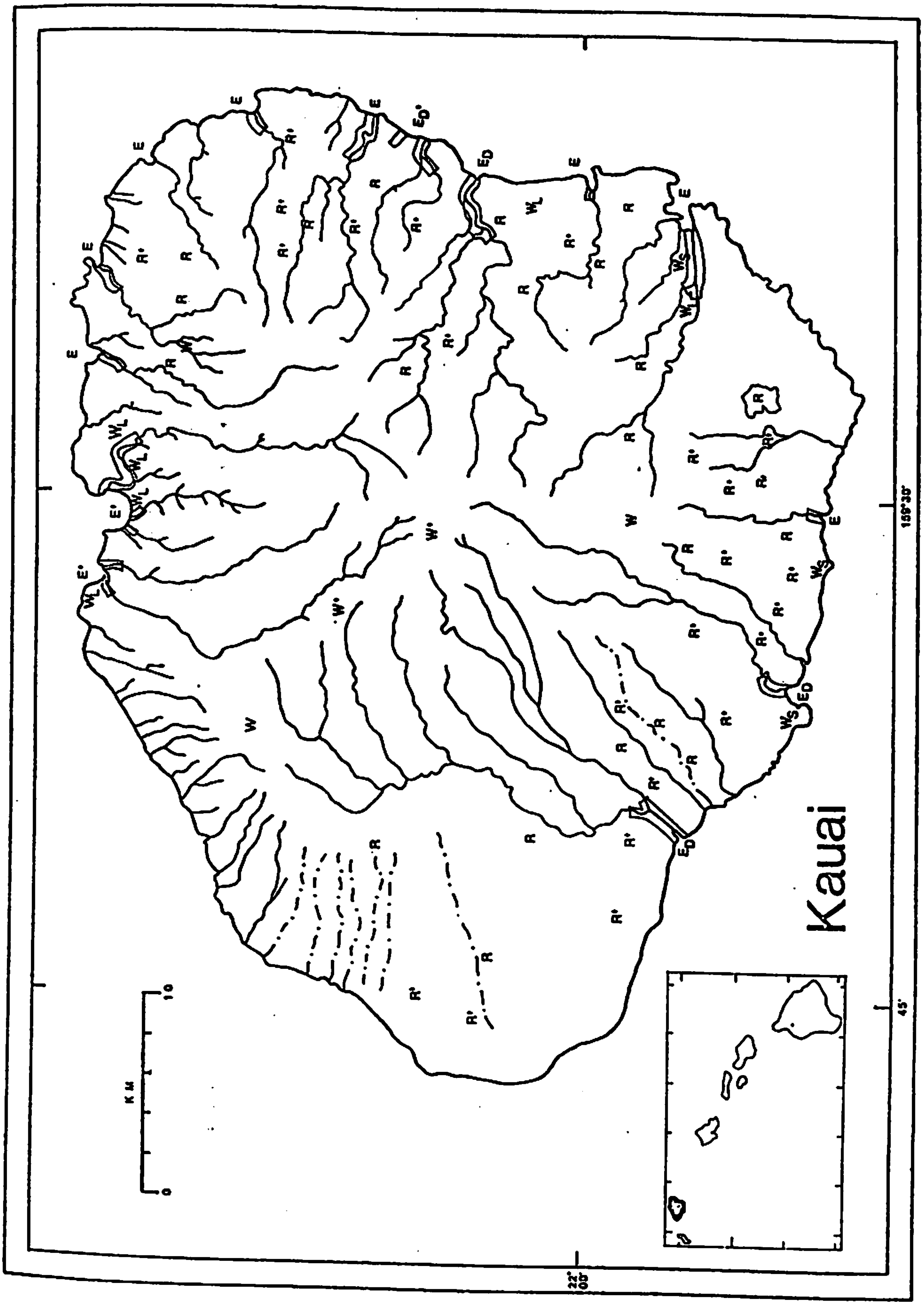
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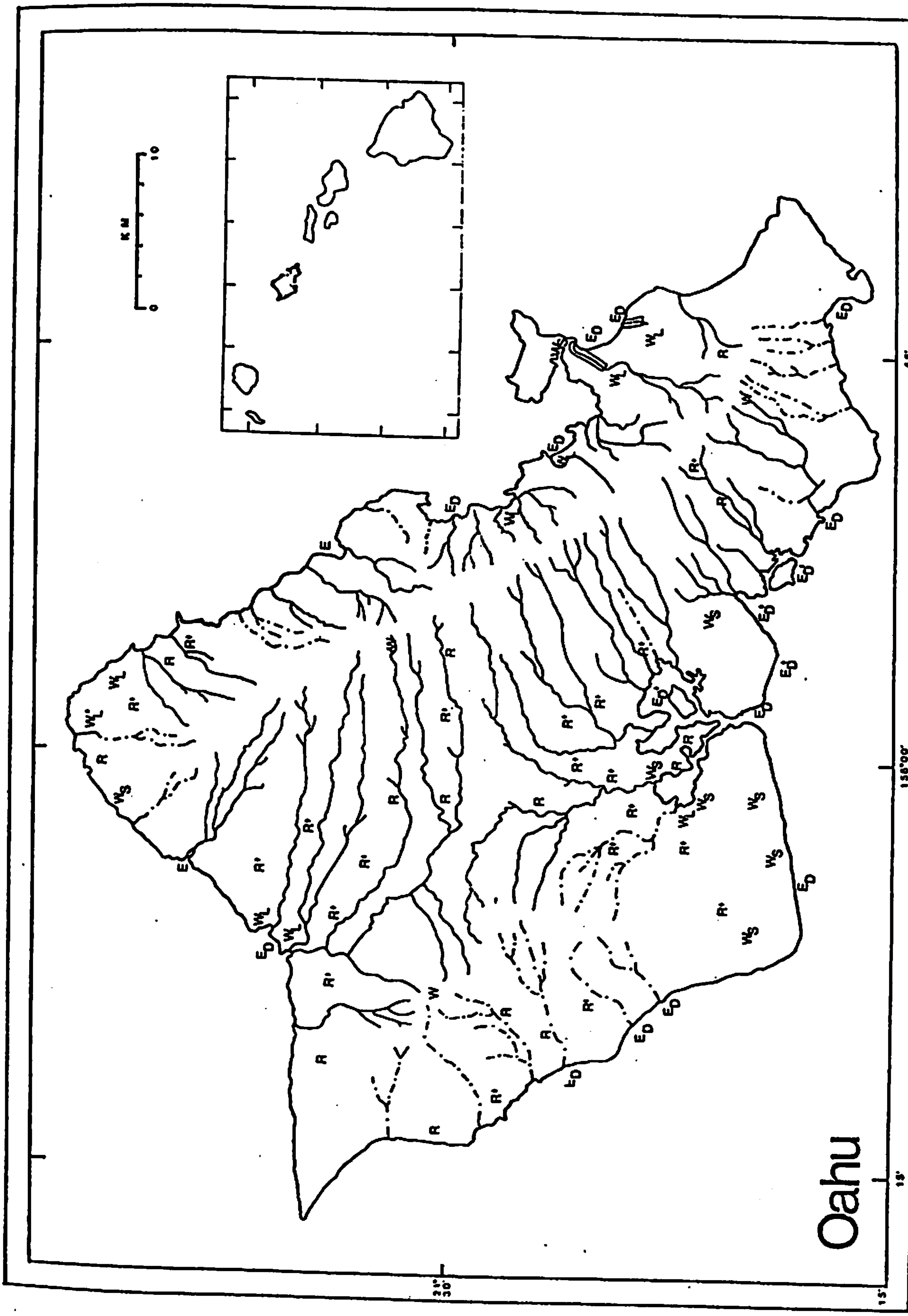
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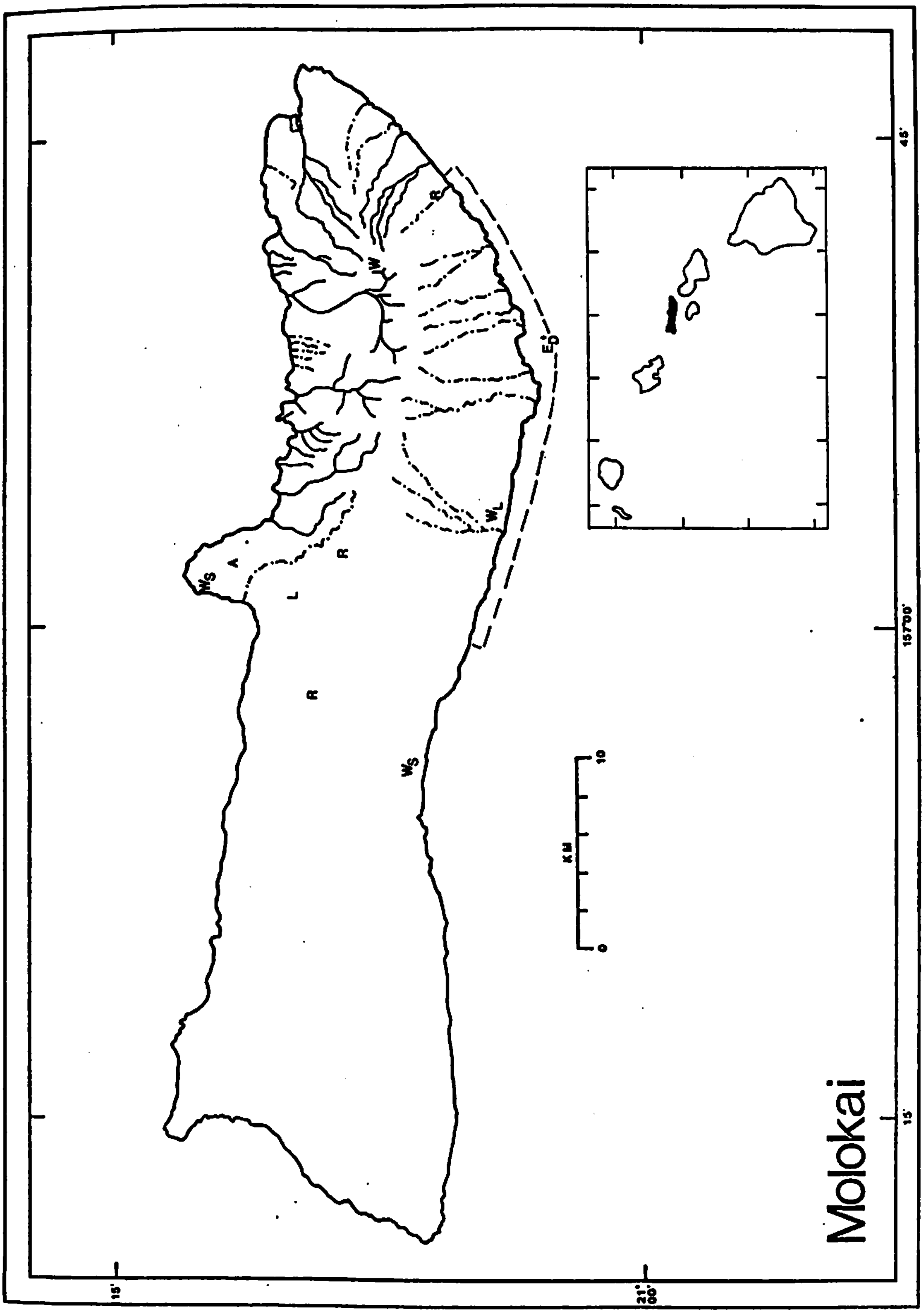
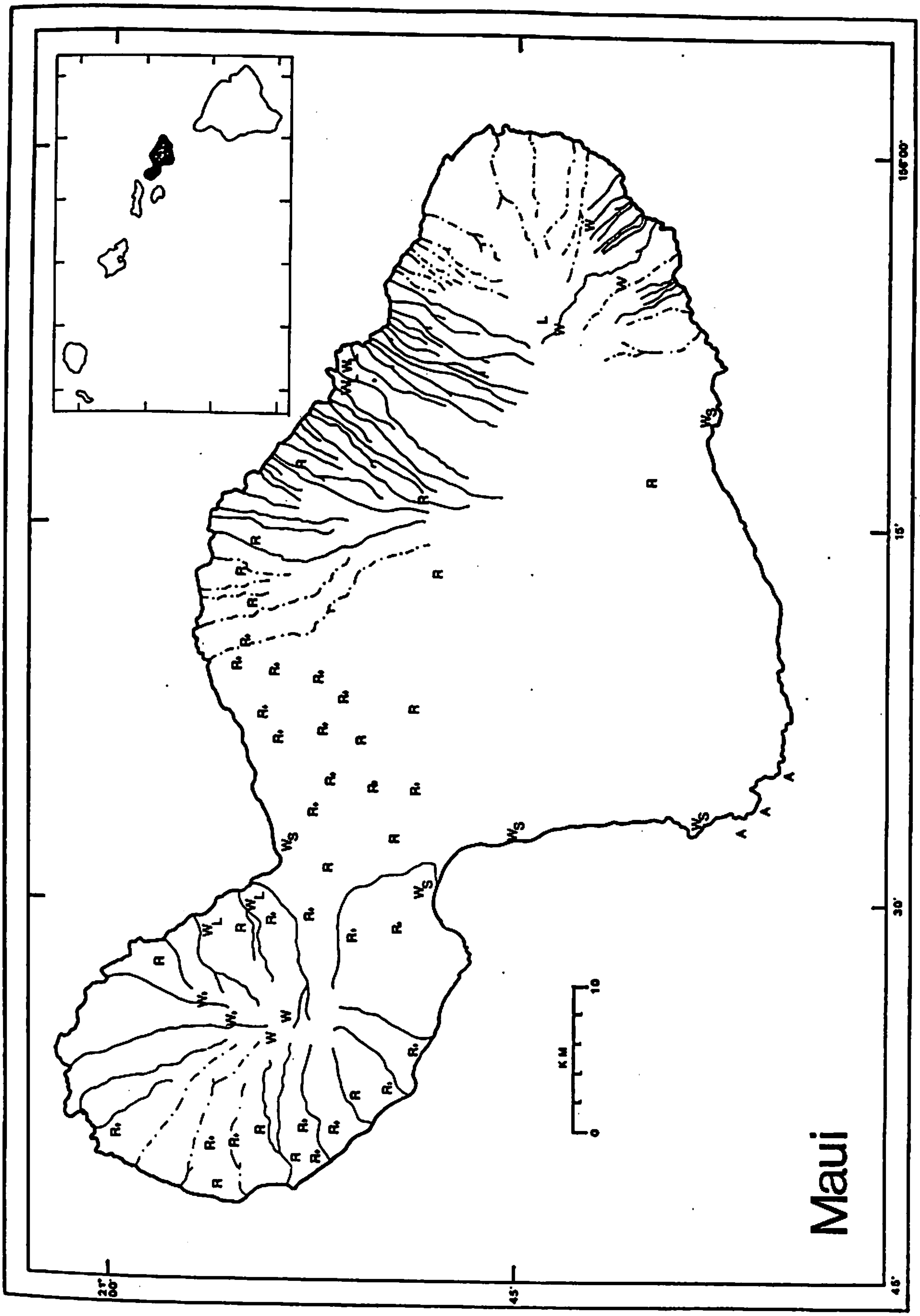
158°00'
15'
21° 30'


Molokai
45'
157°00'
15'
21°00'
15'
KM
0
10


Maui
KM
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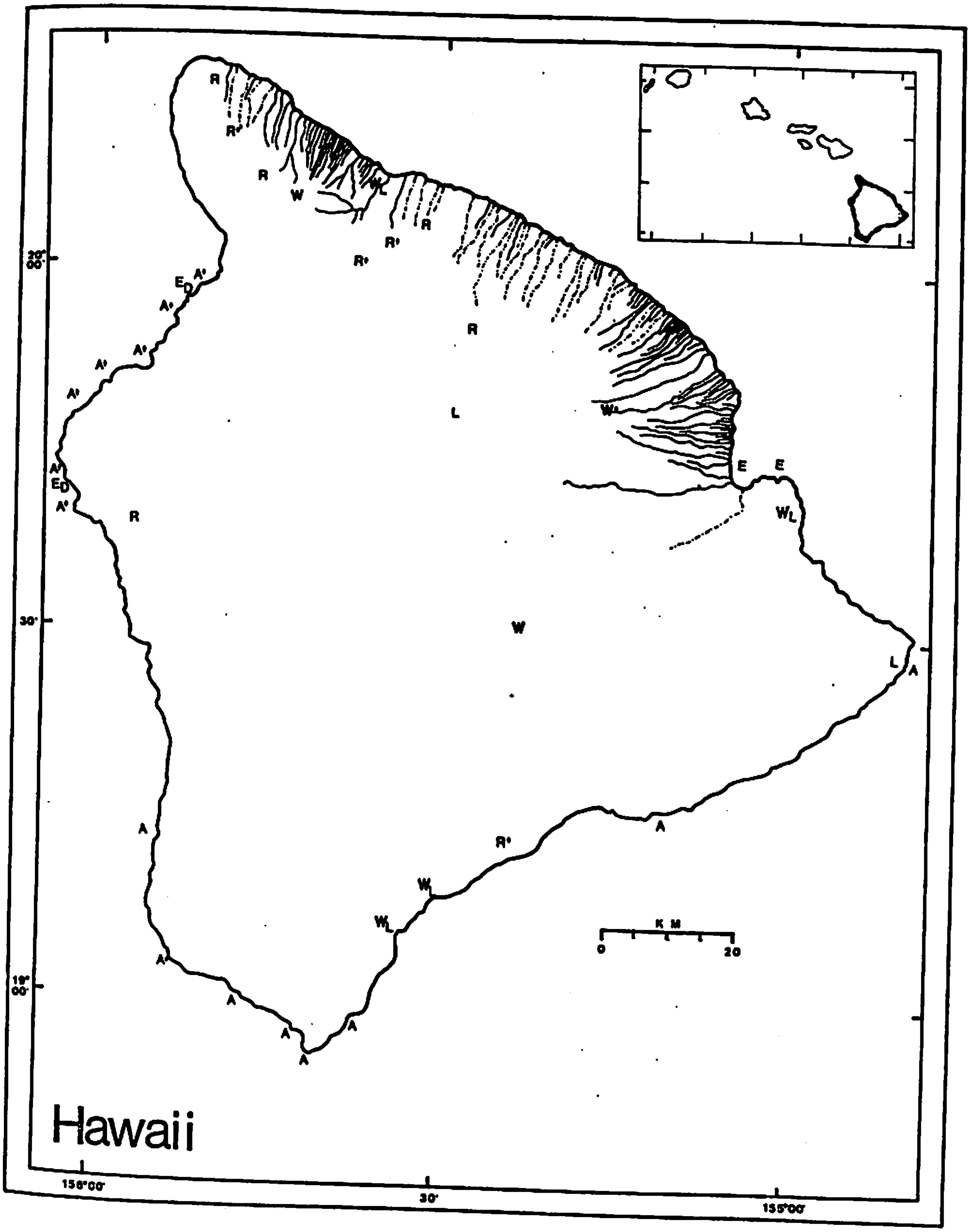
15'
156°00'



S-09-324

Attachment 2

KEY TO HAWAIIAN INLAND WATER ECOSYSTEMS BASED ON ENVIRONMENTAL FEATURES

1. Freshwaters flowing down altitudinal gradients. = Lotic Ecosystems. -- 2.

Fresh or saline standing waters. = Lentic Ecosystems. -- 5.

2 (1). Water in definite natural channels derived all or in part from land surface runoff. May have sections of channels modified. = Streams. -- 3.

Water not in channels or in artificial or indistinct channels. = Ditches or Rheocrenes. -- 4.

3 (2). Flowing water present year-round; variable annual flow volume, most of which results from surface runoff; low flow (dry season) from groundwater sources. = <u>Perennial Streams</u>.

[Two ecological forms distinguishable: Continuous Streams have perennial flow from headwaters to ocean; Interrupted Streams have perennial flow only in part of channel (usually upstream) with seasonal discharge to ocean.]

Water present in channel during part of year only (wet season) all of which is from surface runoff. = <u>Intermittent Streams</u>.

4 (2). Water flowing in channels that are entirely artificial; source generally stream diversions or reservoir outflow. = <u>Ditches and Flumes</u>.

Small, perennial, relatively constant flows not in distinct channels (e.g., wet films or trickles over rock surfaces); water emanating from elevated aquifers. = <u>Seeps and Springs</u>.

[Two types of rheocrenes distinguished: Stream Associated occur in deeply-cut valleys and contribute to stream flow; Coastal are on coastal escarpments and usually flow into ocean.]

5 (1). Standing water that is always fresh (salinity <0.5 $^{o}/oo$). -- 6.

Standing water that is continuously or seasonally saline (salinity >0.5 $^{o}/oo$). -- 9.

6 (5). Deep water (> 2 m) in well defined basins.
= Lacustrine Ecosystems. -- 7.

Shallow water (< 2 m) in more or less indistinct basins.
= Palustrine Ecosystems. -- 8.

7 (6). Water in natural basins. = Natural Lakes.

[Four identified in State.]

Water in artificial basins. = Reservoirs.

8 (6). Natural bogs, ponds, and marshes in undisturbed areas, mainly remote uplands and Forest Reserves.
= Elevated Wetlands.

Ponds and marshes in culturally modified areas (residential, agricultural) usually lowlands as near coast or in valley termini; origin may be natural or man-made. = Low Wetlands.

9 (5). Characteristically mixohaline (salinity 0.5 to 30 $^{o}/oo$) waters in definite basins with continuous or seasonal surface connection to ocean that allows entry of euryhaline marine fauna. = Estuaries.

[Further subdivided into Natural Estuaries that occur mainly at stream and river mouths, and Developed Estuaries that are artificial or strongly modified from natural state such as dredged and revetted stream termini.]

Waters that vary in salinity and basin limits and are not surface-connected to ocean except in rare circumstances. -- 10.

10 (9). Natural mixohaline water exposures near coastline in recent lavas (rarely, fossil reef) and having tidal fluctuations; mostly small shallow pools of low salinity (1 to 10 $^{o}/oo$) with distinctive biota (no fishes). = Anchialine Pools.

Ponds and Marshes having variable salinity and permanence, mainly adjoining coastline; usually without tidal fluctuations and with introduced biota, esp. fishes; natural or man-made. = Coastal Wetlands.

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HAWAIIAN MARINE WATERS

This paper describes an organization of Hawaii's marine waters in such a way that water quality standards can be proposed, monitored and satisfied, in order to maintain the ecological integrity and beauty of our unique marine systems. The need to protect our vulnerable ecological habitats has received ever-increasing emphasis because of escalating multiple-use pressures. The classification proposed here is based upon the variety, distribution and abundance of marine habitats of relevance to water quality management and is not totally descriptive of Hawaiian marine ecosystems.

Although the marine waters of the state flow one into the other, the intimate relationship between seawater and the variety of substrates which come into contact with it provides a basis for subdividing the waters into independent, though related, units. The marine environments in Hawaii are here divided between water types and bottom subtypes. Because no individual bottom subtype is consistently associated with any particular water type, the classifications of these two systems are treated separately.

Adult fishes are unique to the fauna of these two major marine classifications in that they are motile animals frequently found in more than one category and which, in general, do not respond as directly to environmental changes as do their benthic counterparts. Many, however, can be found associated with particular environments more often than others and do respond to the influence of physical-chemical changes on their particular habitat and food supply. The works of Gosline (1965), Gosline and Brock (1960) and Hobson (1974) provide considerable information on the over 700 species of fish found in our waters. Hobson's classification of reef fishes off Kona, Hawaii has been used extensively throughout this report.

Quantification has been avoided in statements regarding fishes and other biota associated with the classification scheme. Even the designation of presence versus absence of species can introduce serious errors into ecological implications. Certainly many living forms are active diurnally while others are nocturnal only and secretive or cryptic species are frequently under-represented. Nevertheless, an attempt is made to identify as many forms of life representative and characteristic of each classification for the purposes of categorization as well as enforcement of water quality standards.

While bottom communities are typically categorized on the basis of physical substrate and species composition or diversity, water type communities can, for water quality considerations, be characterized (except fishes) on the basis of abundance (biomass) and/or production rates. Biomass considerations are presently more attractive.

Phytoplankton, the primary producers of the pelagic food web, provide a focal point for identifying water body categories. Factors which influence phytoplankton ecology will ultimately affect the rest of the food web. Thus, our Hawaiian marine water types have been categorized on the basis of phytoplankton biomass and/or parameters which influence biomass. The environmental parameters we are most concerned with here are those which influence photosynthesis and associated growth rate responses such as:

1) light availability

2) nutrient availability

3) toxins or antimetabolites

Our oceanic system provides good light penetration, low available nutrient supply and low biomass. As we move shoreward, light penetration decreases, nutrient availability increases, biomass increases and toxins increase (especially in industrial or heavy commercial areas). For monitoring purposes, it is advantageous that the parameters used to identify these areas are quantifiable and do not require highly specialized taxonomists.

Marine Water Types

In order to reflect the natural variability of our marine water bodies and for purposes of establishing a water quality monitoring program, the marine waters have been divided, based upon their relationship to land masses, into four types--embayments, open coast, transition zone and open ocean. (See Figures 1-4.) This particular categorization has been selected because of its usefulness in providing relevance and simplicity to water quality monitoring. These four types have been defined in terms of their water chemistry, hydrography and distinguishing biota. The descriptions are not intended to be absolute but meant as interim, pragmatic definitions for a marine waters classification scheme. The classification of a particular water body is not based on a single descriptive parameter, but instead based on the combination of all descriptive parameters that best characterize a particular water type. The limits placed on various defining parameters are based on existing information for Hawaiian waters, however, there is built-in flexibility for future modification as new data becomes available.

Embayments

Not all bays are embayments. Embayments are characterized by restricted entrances to open coastal waters and are generally confined and physically protected bodies of water. It is necessary to define a threshold which separates embayments from open bays. The distinguishing factor is that in embayments a smaller fraction of water is exchanged during each tidal cycle.

Information Relating to Maps of Marine Water Types

- - - - - - - - - - - Coastal Waters 100 Fathoms
(600 Feet or 183 Meters)

——— 3 Mile Territorial Limit

— — — Oceanic Waters 500 Fathoms
(3,000 Feet or 914 Meters)

Coastal Waters

Transition Zone

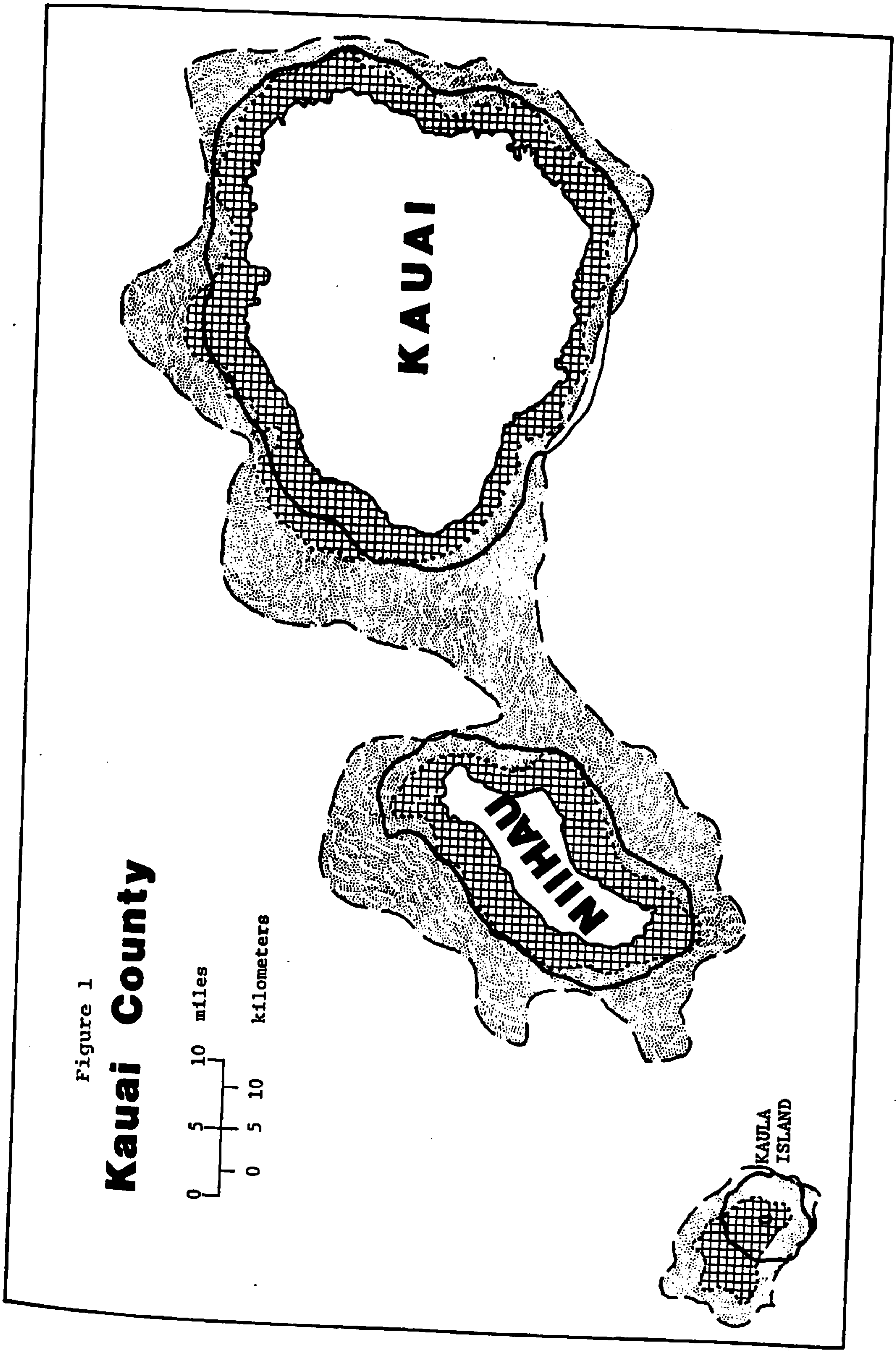


Figure 1
Kauai County

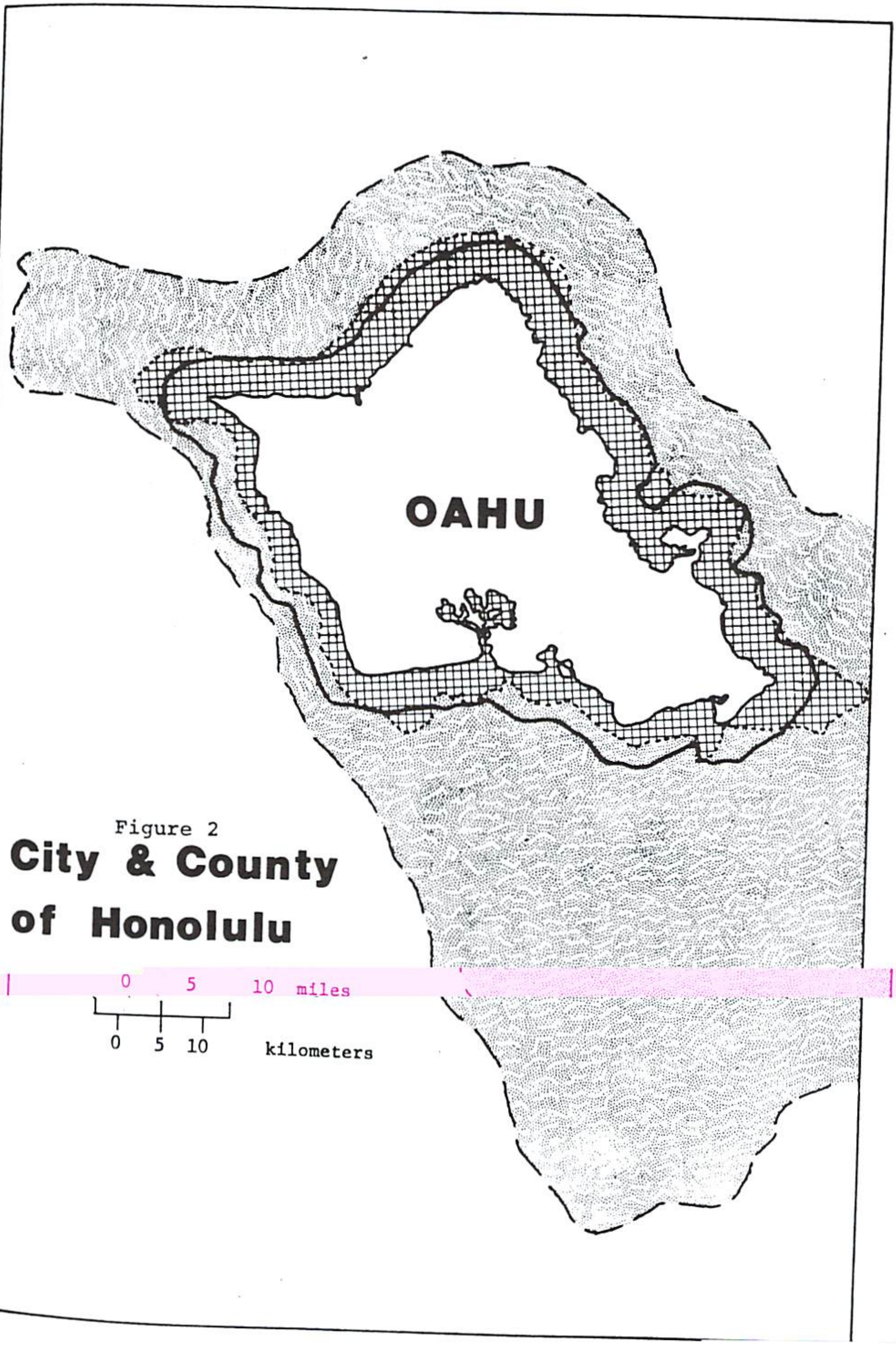


Figure 2
City & County of Honolulu

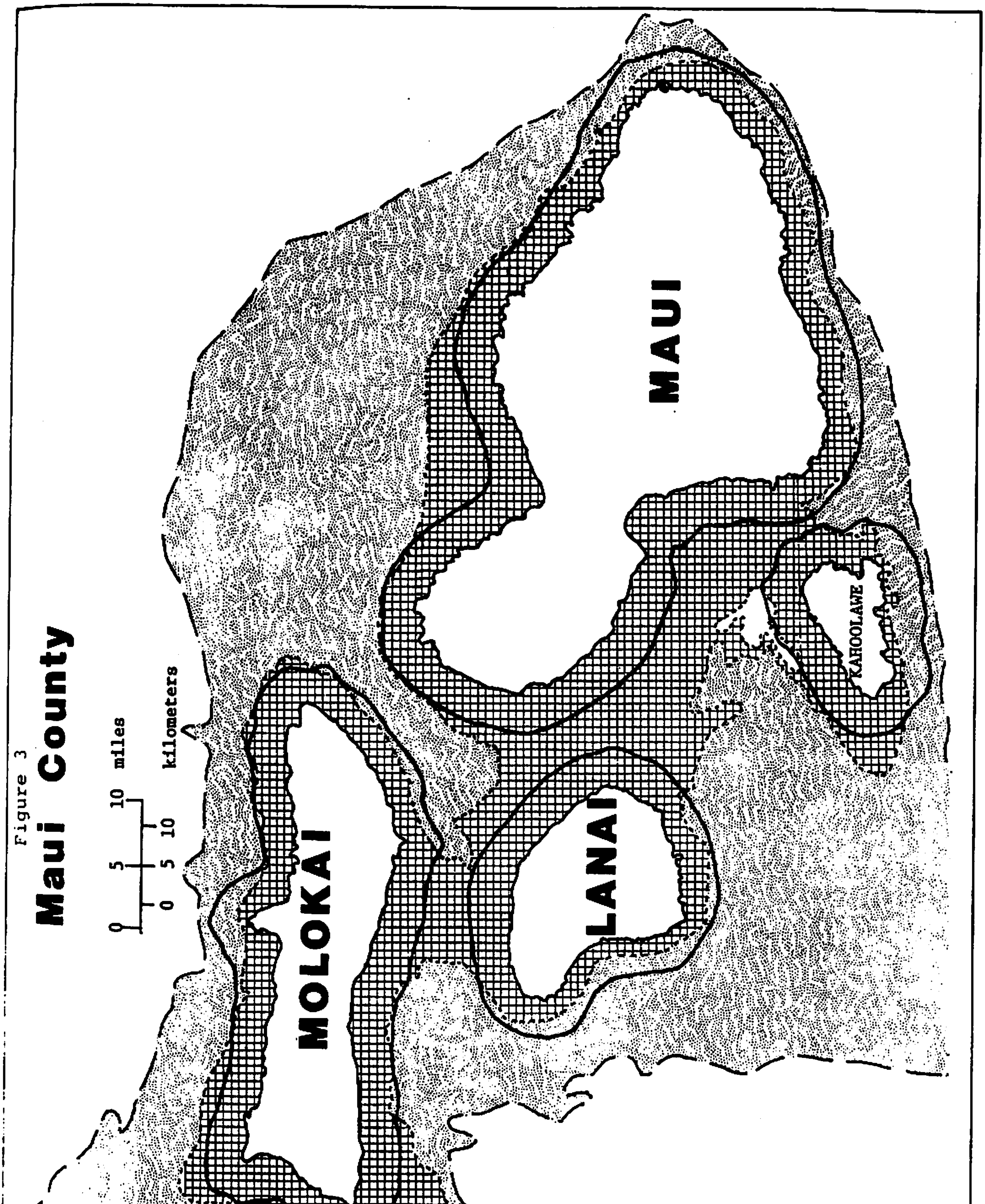


Figure 3
Maui County
0 5 10 miles
0 5 10 kilometers
MOLOKAI
LANAI
MAUI
KAHOOLAWE

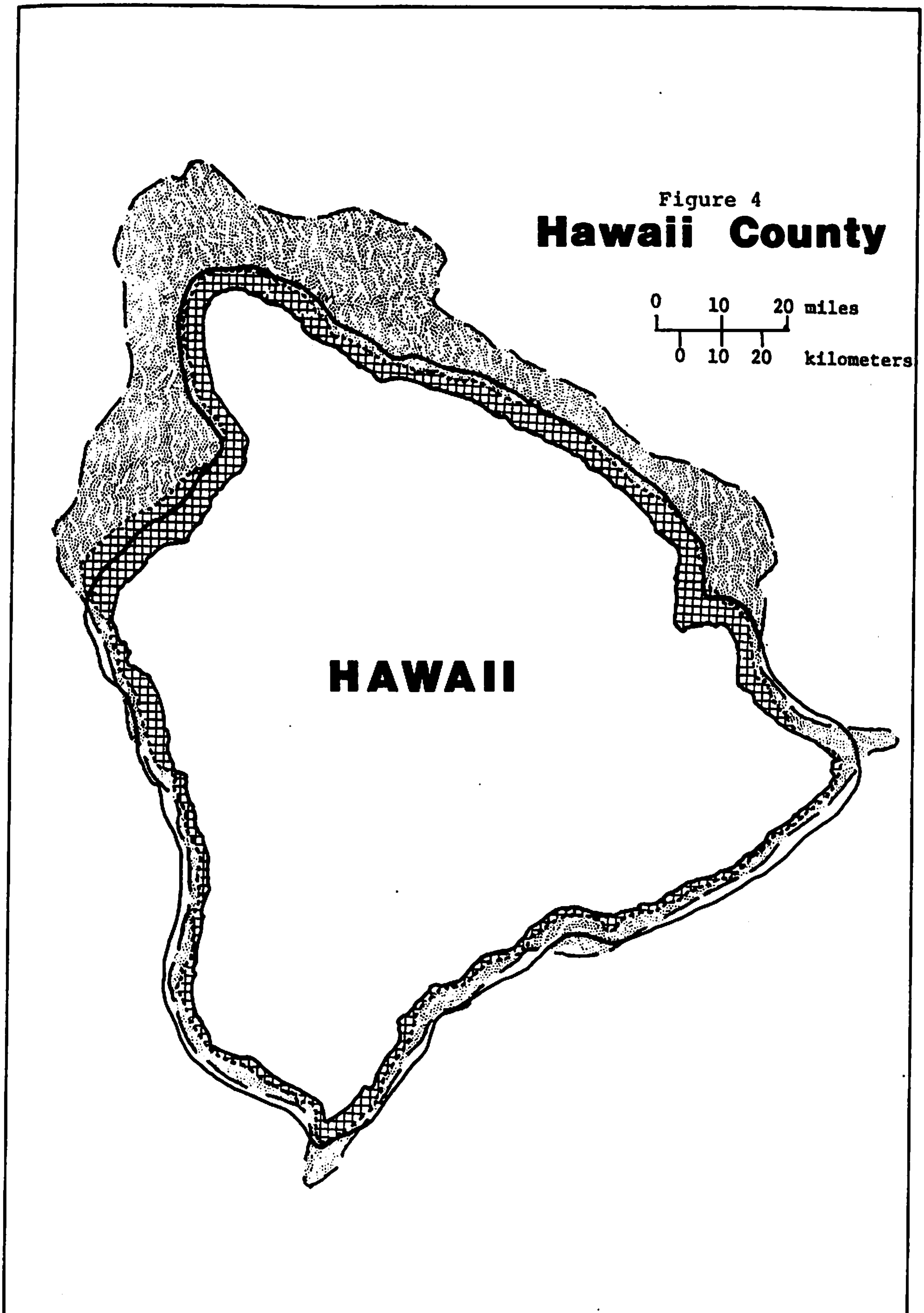


Figure 4
Hawaii County
0 10 20 miles
0 10 20 kilometers
HAWAII

The ratio of a bay's total volume to the cross-sectional area of its entrance was used to establish its degree of enclosure. The threshold, separating embayments from open coastal waters, appears to occur when the ratio of total volume to cross-sectional entrance area reaches 700 to 1.

A crude but useful approximation of residence time in embayments is the ratio of the total volume of the water body (volume at MLLW plus tidal prism volume plus daily discharges of surface and groundwater from the land) to the tidal prism volume (the volume of water which, in theory, is replaced by the daily change in tidal height acting over the surface area of the water body). This ratio was computed for water bodies which qualified as embayments under the other threshold. The ratio of total volume to tidal prism volume for embayments was on the order of 7 to 1 or larger. The tidal prism method ignores other less predictable factors that are involved in water exchange such as wind, storm waves, and density currents. Nevertheless, it appears that a residence time of a few days is sufficient to allow enclosed water bodies to acquire the characteristics of embayments. Because of slow flushing, pollutants introduced to embayments may be able to settle out or become available to organisms in higher concentrations. Water quality problems in embayments tend to persist. After the source of stress is relaxed, recovery may take years.

The following is a list of example bays that either do or do not fall into the embayment category.

<u>Embayments</u>

Big Island:
- Hilo Bay
- Kailua Boat Harbor

Kauai:
- Hanamaulu Bay
- Inner portions of Nawiliwili Bay
- Hanalei Bay

Maui:
- Kahului Bay

Oahu:
- Kaneohe Bay

<u>Not Embayments</u>

Maui:
- Maalaea Bay

Kauai:
- Nawiliwili Bay seaward of breakwater
- Wailua Bay

Oahu:
- Waimanalo
- Kailua Bay
- Maunalua Bay

Three water chemistry parameters are additionally useful in evaluating the existence of an embayment. These parameters--light attenuation, chlorophyll _a_, particulate carbon--were selected on the basis of their usefulness in providing relevant information and the relative ease with which they may be sampled and/or measured. They are inter-related since they all deal with various aspects of particulate matter. The three parameters together will accurately reflect the water classification. The extinction coefficient, a measure of light attenuation and, therefore, particle density, is a valuable parameter for distinguishing embayments from other water bodies. It should be measured with a k type meter (vertical measure) and will generally be greater than 0.15 in embayment waters, where poor flushing leads to greater particle density.

Chlorophyll a is another valuable measurement for distinguishing between marine water types. Embayments are defined as having a chlorophyll a concentration of > 0.50 ug/l.

Although chlorophyll a determinations can be used to assess phytoplankton biomass adequately, particulate-organic-carbon (POC) values reflect both living and non-living material in the water column. Thus, POC can augment the chlorophyll measurements and the light extinction coefficient in defining the marine water bodies. Embayments can be defined with POC values greater than 150 ugC/l.

In order to incorporate the influence of land drainage on embayment water-quality characteristics, it was necessary to recognize three subclasses, depending on whether they received perennial runoff, seasonal runoff or little to no runoff from the land. (See Figures 5-12 for maps depicting embayments with these subclassifications for each of the islands.) These classifications require the establishment of thresholds. Data are insufficient to make a quantitative determination of every body of water. However, data-rich areas were used to approximate the ranges of freshwater discharges associated with the three classes of embayments.

Embayments Receiving Perennial Runoff from Land (Wet Embayments)

In wet embayments, which receive perennial discharges from streams or shoreline springs, freshwater inflow approaches 1% of the total water volume per day. A cold water lens of brackish water forms over higher salinity ocean waters. This lens usually extends about 1 meter below the surface and is usually confined to within 1,000 feet of the shoreline. Although the brackish water layer is present year round, it expands after heavy rainfall and becomes much more noticeable. The brackish water lens is more noticeable in embayments where mixing is poor. Terrestrial influences greatly modify this subclass.

Embayments Receiving Seasonal Runoff from Land (Seasonably Wet Embayments)

In seasonally wet embayments, a brackish water lens may form only during periods of high rainfall, when intermittent streams and

Information Relating to Maps of Embayments and Open Coastline

OPEN COASTAL WATERS

Perennially Wet

Seasonally Wet

Perennially Dry

KNOWN EMBAYMENTS

● Wet

◒ Seasonally Wet

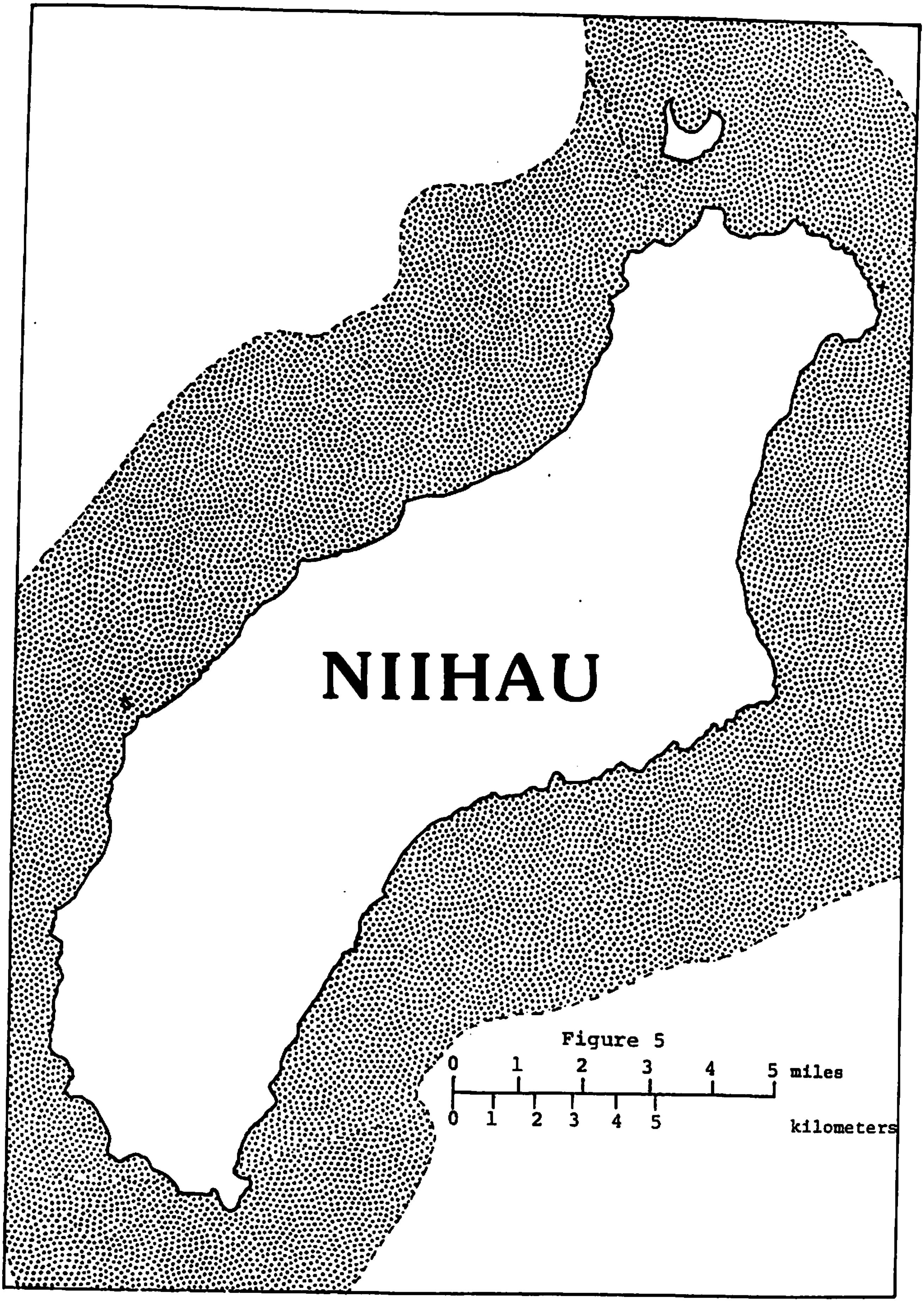
○ Dry

SUSPECTED EMBAYMENTS

■ Wet

⬓ Seasonally Wet

□ Dry



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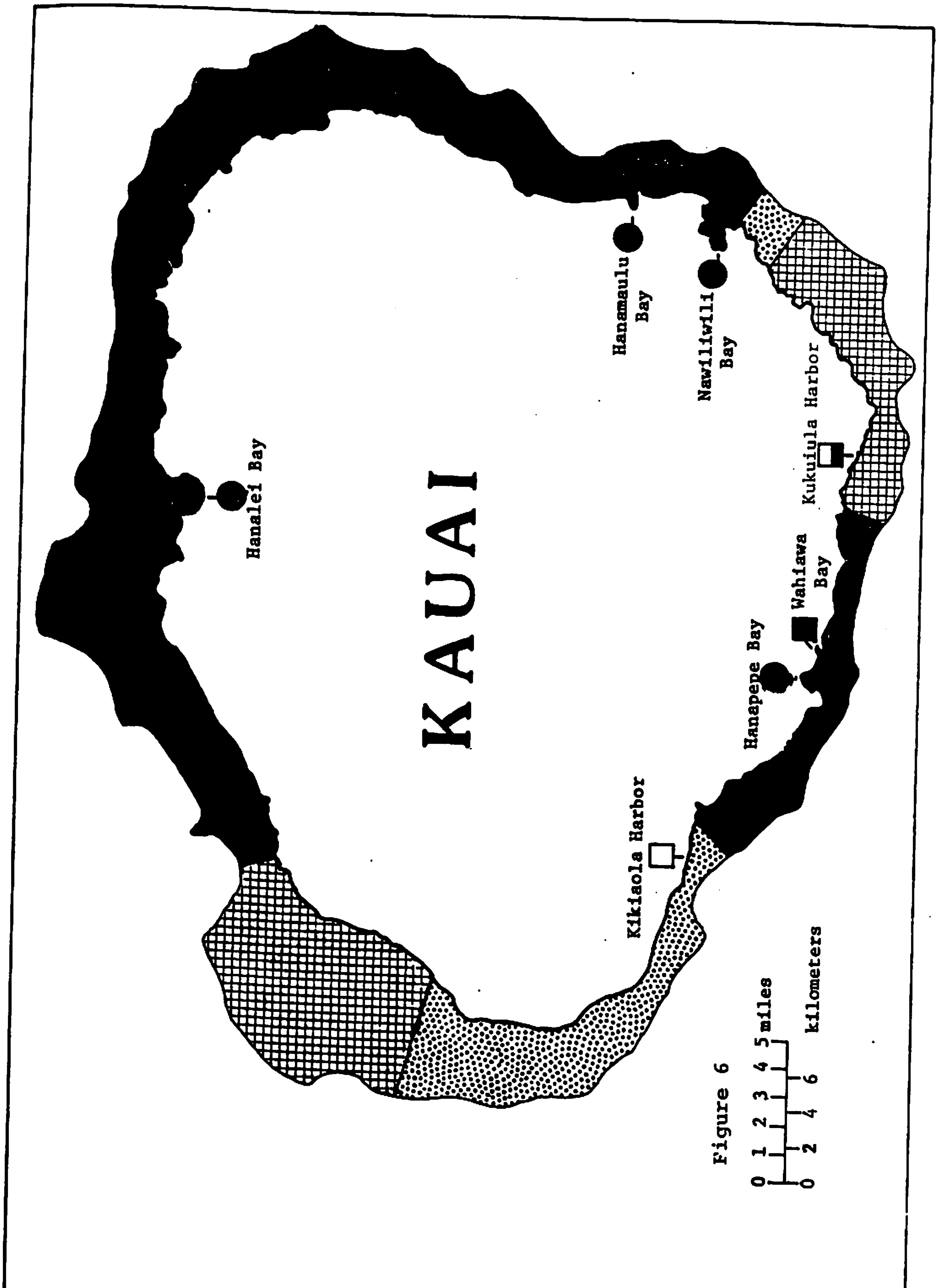

KAUAI
Hanalei Bay
Hanamaulu Bay
Nawiliwili Bay
Kukuiula Harbor
Wahiawa Bay
Hanapepe Bay
Kikiaola Harbor
0 1 2 3 4 5 miles
0 2 4 6 kilometers

Figure 6

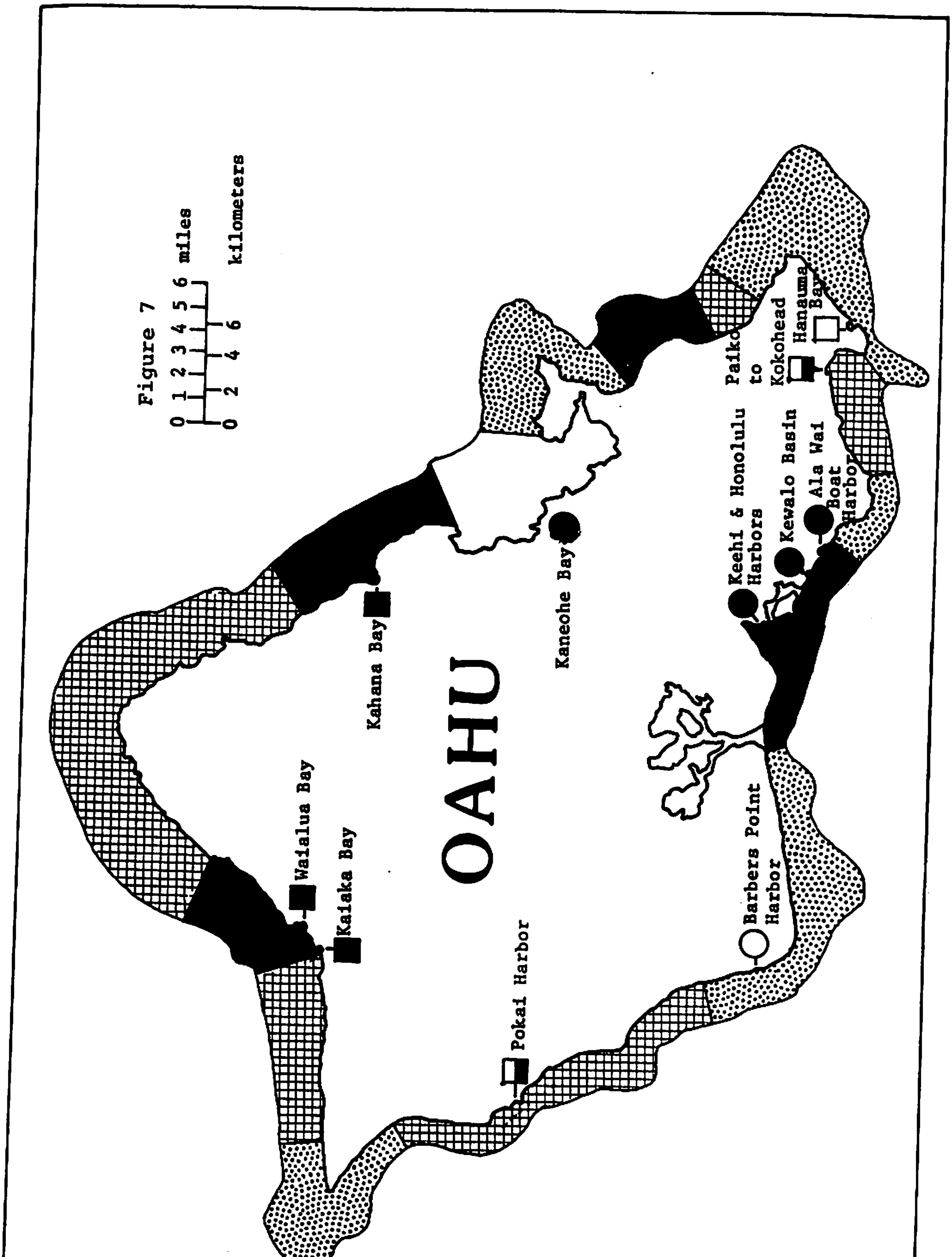

0 1 2 3 4 5 6 miles
0 2 4 6 kilometers
OAHU
Waialua Bay
Kaiaka Bay
Kahana Bay
Kaneohe Bay
Pokai Harbor
Barbers Point Harbor
Keehi & Honolulu Harbors
Kewalo Basin
Ala Wai Boat Harbor
Paiko to Kokohead
Hanauma Bay

Figure 7

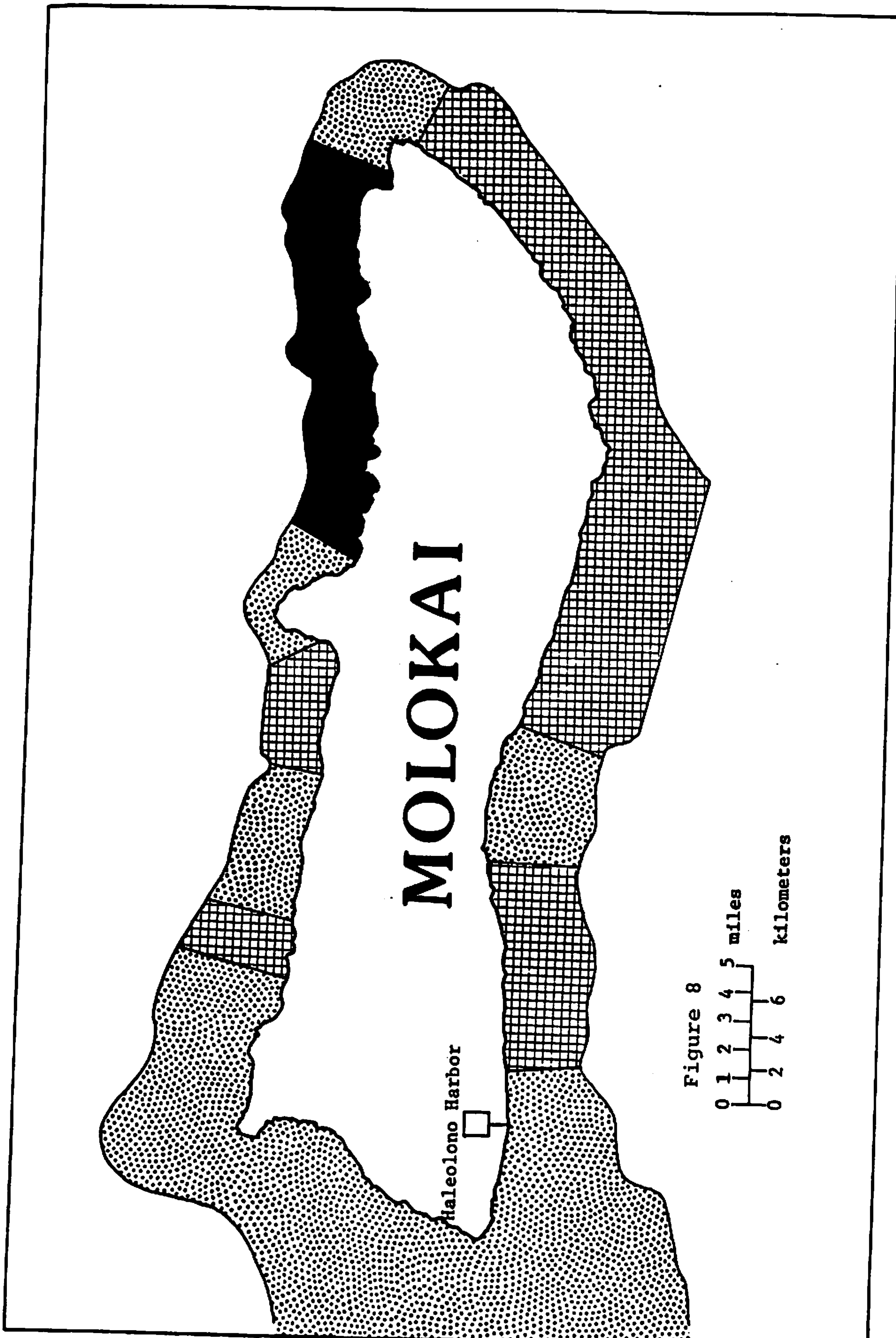


Figure 8

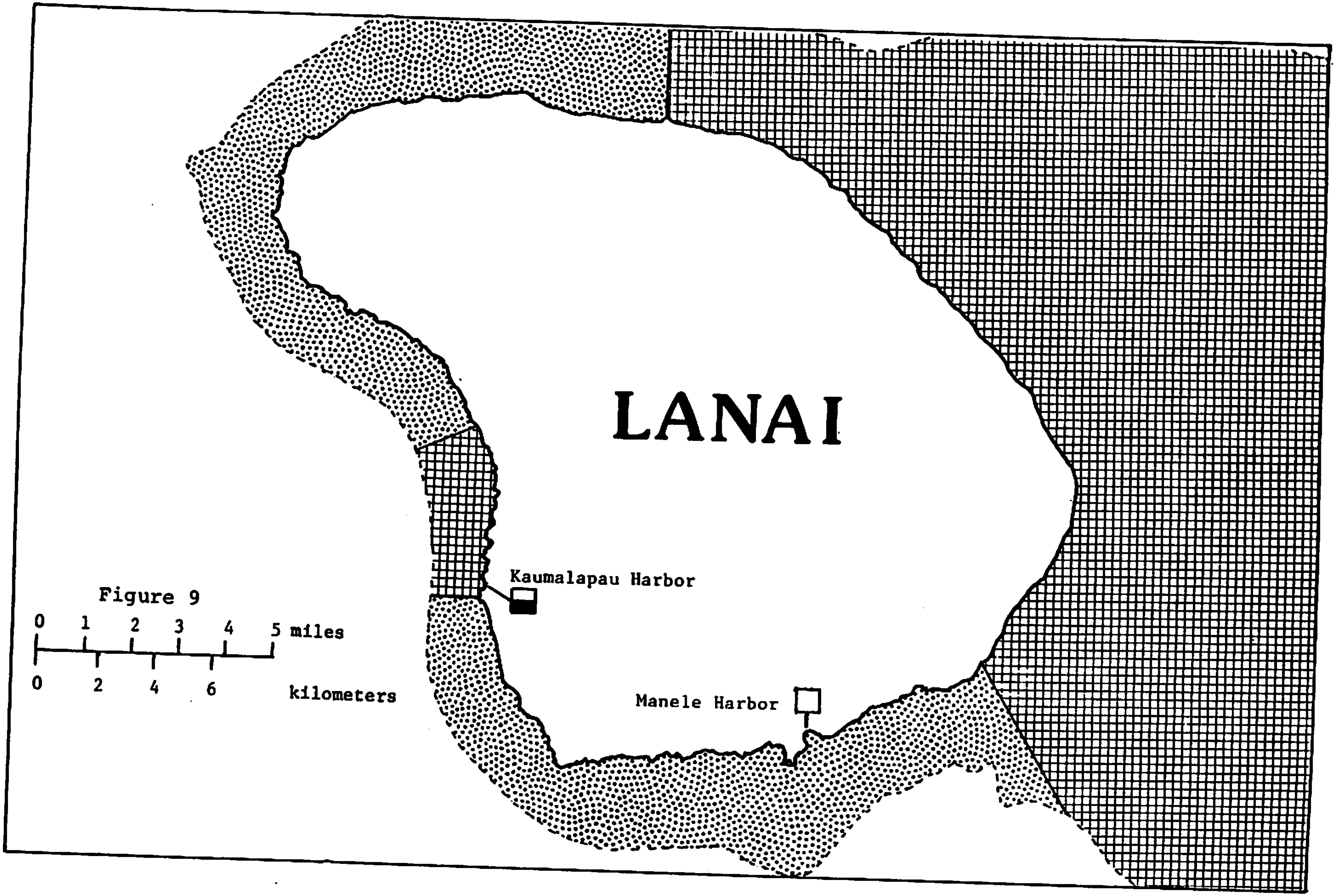

LANAI
Kaumalapau Harbor
Manele Harbor
0 1 2 3 4 5 miles
0 2 4 6 kilometers

Figure 9

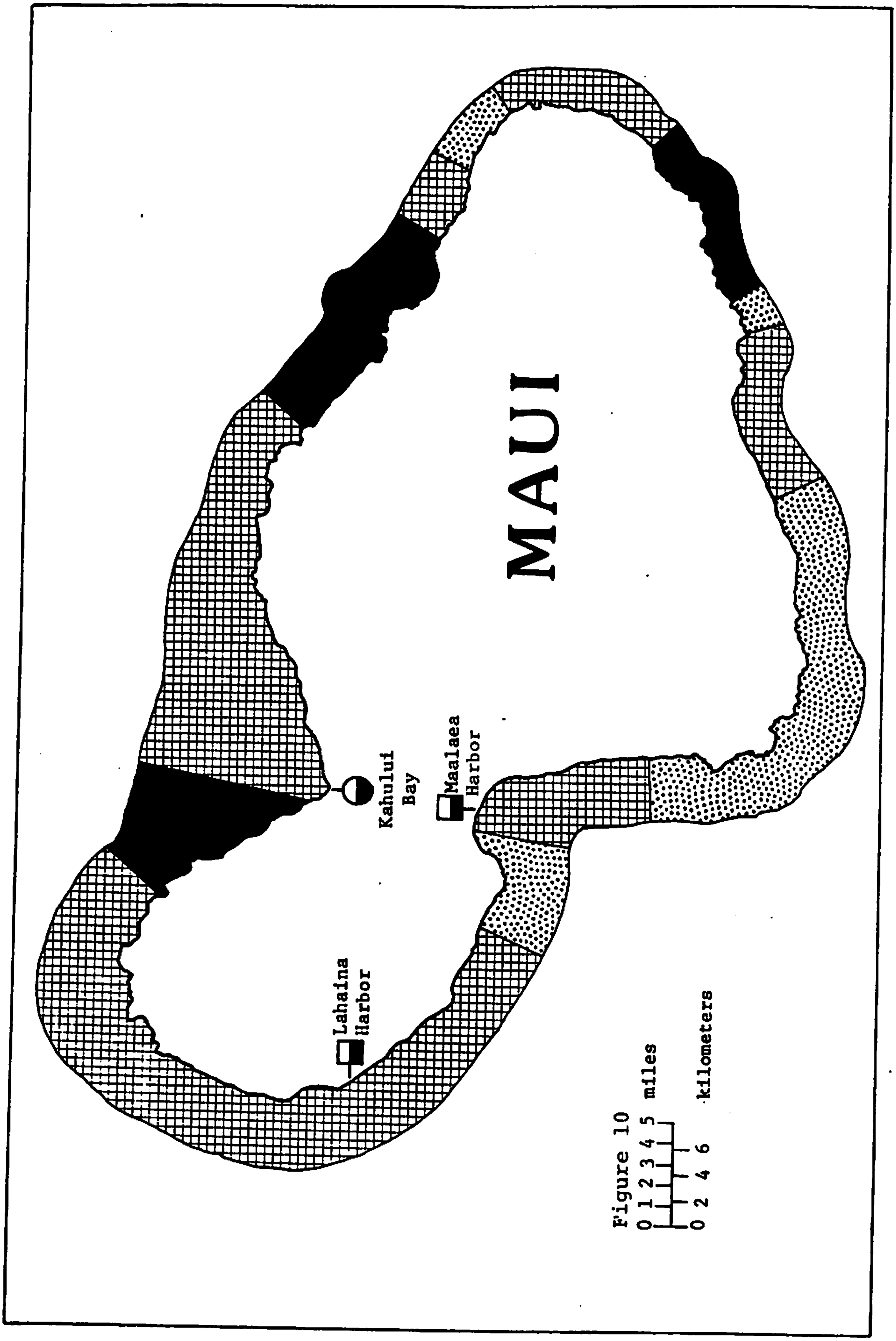

MAUI
Kahului Bay
Maalaea Harbor
Lahaina Harbor
0 1 2 3 4 5 miles
0 2 4 6 kilometers

Figure 10

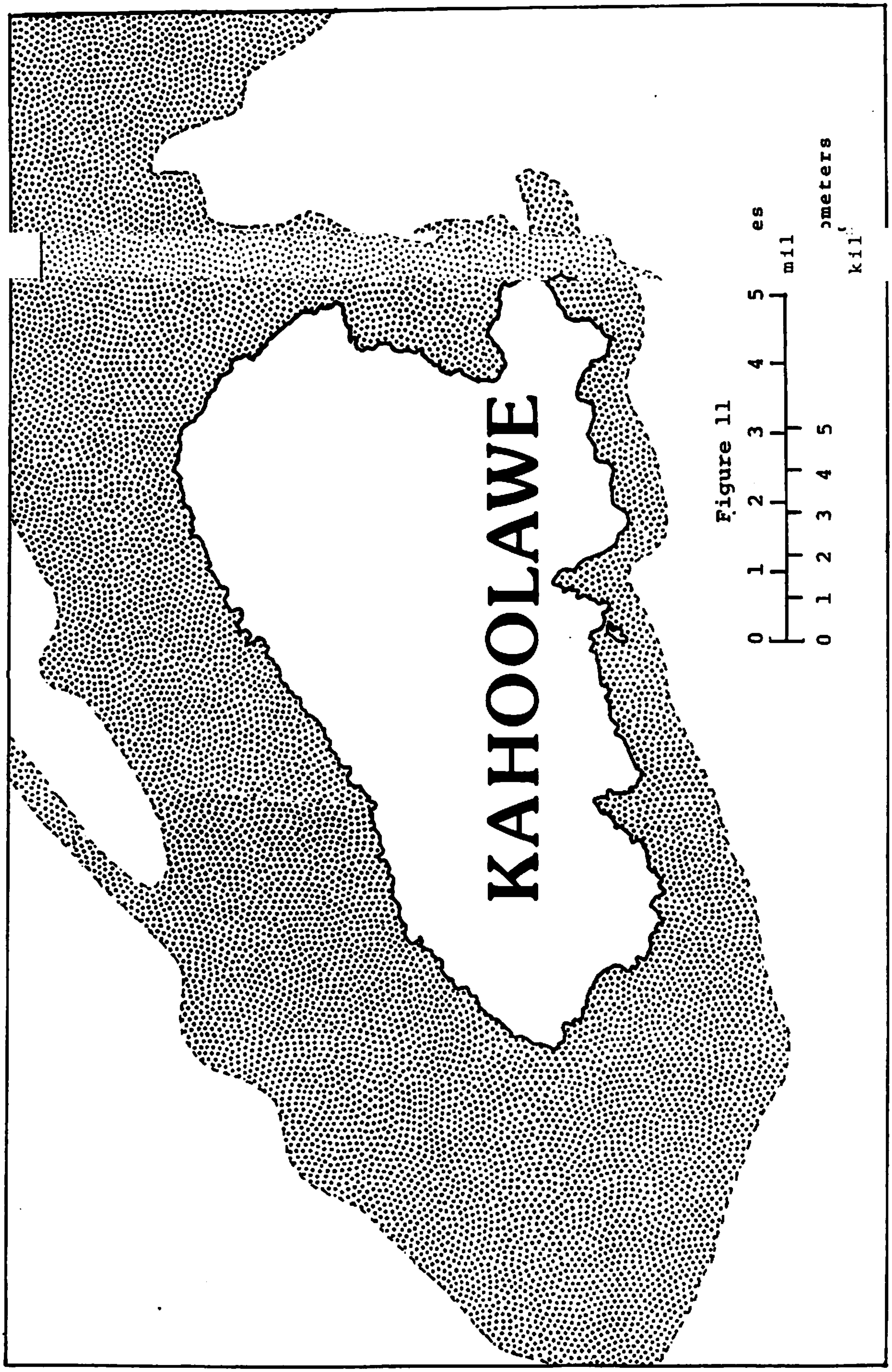


Figure 11

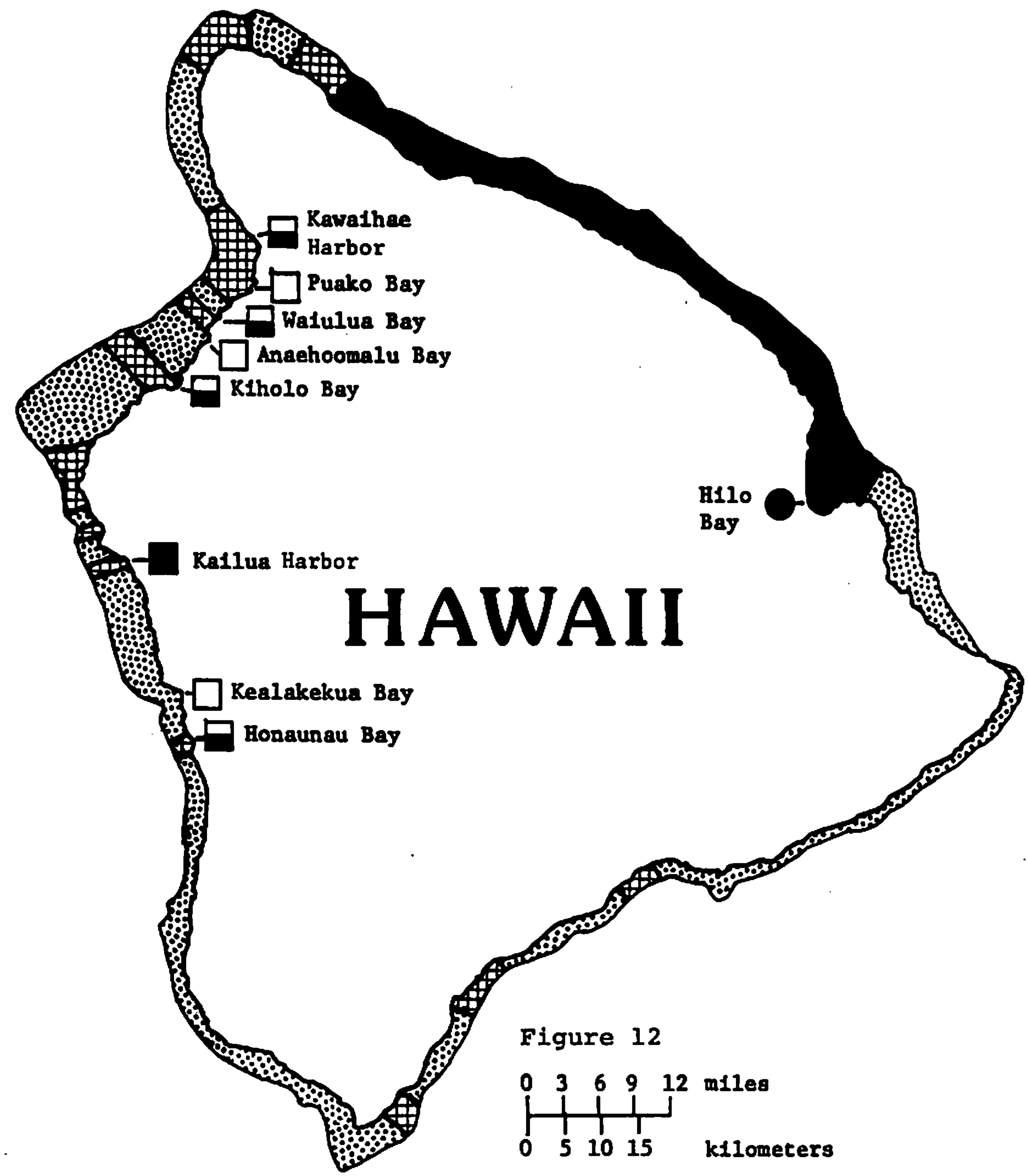

Kawaihae Harbor
Puako Bay
Waiulua Bay
Anaehoomalu Bay
Kiholo Bay
Hilo Bay
Kailua Harbor
HAWAII
Kealakekua Bay
Honaunau Bay
0 3 6 9 12 miles
0 5 10 15 kilometers

Figure 12

shoreline springs discharge significant runoff. At these times, the surface layer of the water column is cold and brackish and freshwater inflow approaches 1% of embayment volume per day. At other times of the year, embayment waters maintain "normal" temperature and salinity. Terrestrial runoff exerts sporadic influence on this subclass.

Embayments Receiving Little or No Runoff from Land (Dry Embayments)

Dry embayments never receive significant discharges from streams or shoreline springs. Runoff to these water bodies is limited to coastal drainage from the immediate shorelands and is insufficient to form a brackish water lens. There is little terrestrial influence on this subclass.

A variety of plant and animal life is associated with embayments. Some of the adult fishes include the omaka, *Caranx mate*, the eleotrid *Asterropteryx semipunctatus*, the nehu *Stolephorus purpureus*, the iao *Pranesus insularum*, the makiawa *Etrumeus micropus*, the lizardfish *Saurida gracilis*, the barracuda *Sphyraena barracuda* and the mullets *Mugil cephalus* and *Chelon engeli*.

Larval fishes captured in embayments have adult stages which occur primarily in open ocean waters. In fact, the relative abundance and assortment of larval fishes bear little relationship to the embayment-residing adult species. Surgeon fish, wrasses, parrotfish and butterfly fish, which are prominent in Kaneohe Bay as adults, are not present in their larval stages. In addition, larvae of fish which are strictly deep dwelling, such as myctophids, gonostomatids, microdesmids and lampridiforms, were collected as larvae in shallow Kaneohe Bay. This larval fish information (Miller, 1974) emphasizes the utility of embayments as nursery grounds for a variety of fish species found in other areas of the Hawaiian Islands.

Other biota include certain characteristic species of copepods, diatoms and dinoflagellates. These are quite varied and plentiful and present a rich food source for the larval fishes. See Table 1 for their scientific names.

Open Coast

The open coast is defined as water, other than embayments, occurring from the shoreline out to the 100 fathom contour lines. Open coastal waters may also be defined, using chemical parameters, such as having a k value between 0.10 - 0.50, a chlorophyll *a* concentration between 0.15 - 0.90 ug/l and a POC value between 50 - 150 ugC/l. This water is still under terrigenous influence and inter-island effects such as shoaling occur in this zone. Relative shallowness creates surge and water movements which can maintain suspension of some bottom sediments.

TABLE 1

WATER COLUMN BIOTA

Embayments

Copepods:
- Acrocalanus intermis
- Euterpina acutifrons
- Oithona simplex
- Oithona nana

Diatoms:
- Skeletonema costatum
- Chaetoceros curvisetus

Dinoflagellates:
- Noctiluca scintillans
- Prorocentrum gracilis
- Prorocentrum micans
- Ceratium furca
- Ceratium fusus

Sergestid shrimp:
- Lucifer chacei

Larvacean:
- Oikopleura longicauda

Open Coastal

Copepods:
- Undinula vulgaris
- Labidocera cf. madurae
- Acartia cf. hamata

Transition

Combinations of coastal and oceanic species

Oceanic

Copepods:
- Candacia bipinnata
- Candacia catula
- Pleuromamma xiphias
- Pleuromamma abdominalis
- Neocalanus robustior
- Calanus tenuicornis

Chaetognath:
- Pterosagitta draco

Diatoms:
- Rhizosolenia robusta
- Rhizosolenia acuminata
- Rhizosolenia castracanei

Euphausiids:
- Euphausia tenera
- Euphausia diomediae
- Nematobrachion sexpinosus
- Nematobrachion flexipes

Deep-living Oceanic - always greater than 500 m

Copepods:
- Lucicutia bicornuta
- Paraeuchaeta rubra
- Bathycalanus bradyi

Chaetognaths:
- Sagitta macrocephala
- Eukrohnia fowleri

Euphausiids:
- Thysanopoda cornuta
- Bentheuphausia amblyops

Open coastal waters have been further subdivided into dry, wet and seasonally wet waters in order to account for surface and ground water runoff effects. Dry, open coastal waters have been defined as receiving less than 0.5 million gallons per day of fresh water stream discharge per shoreline mile. Wet open coastal waters receive greater than 3 million gallons per day of fresh water stream discharge per shoreline mile and seasonally wet waters receive greater than .5 but less than 3 million gallons per day per shoreline mile. (See Figures 5-12 for maps of open coastal waters).

Three species of copepods are characteristically found in open coastal waters--*Undinula vulgaris*, *Labodocera cf. madurae* and *Acartia cf. hamata*. The following commercial species of fishes are also found in these waters--akule, *Trachurops crumenopthalmus* and opelu, *Decapterus pinnulatus* as well as kawakawa, *Euthynnus yaito*.

Transition

The transition zone has been defined as the waters occurring between the 100 and 500 fathom contours. This water type was established due to the absence of a clearcut break between the open coastal waters and the open oceanic waters. It is relatively free of bottom and terrestrial effects and contains a mixture of coastal and oceanic biota.

Open Ocean

Open ocean waters are defined beyond the 500 fathom contour and are characterized by good light penetration, low available nutrient supply and low biomass. The k value is generally <0.10, the chlorophyll *a* value is <0.20 ug/l and the POC value is <50 ugC/l. Characteristic planktonic species are listed in Table 1. The migratory tuna species, ahi (*Thunnus albacares*) and aku (*Katsuwonus pelamis*), as well as marlin and mahimahi are fished in these waters.

Marine Bottom Subtypes

The Hawaiian marine bottom subtypes have been categorized on the basis of physical substrate and species composition and diversity so that each category, though related to the others, can stand independently from a water quality management viewpoint. Although species are listed for each category, we feel it important to view each category in terms of assemblages and communities which contain a variety of different species rather than the individual species themselves. Many species are found in more than one category and alone cannot represent an appropriate ecological picture. Most species in nature tend to be associated in their distribution with certain others because they generally exhibit the same tolerances to their physical-chemical-biological environment.

The marine bottom subtypes are divided into the following categories:

- Lava Rock Shorelines
- Sand Beaches
- Solution Benches
- Marine Pools and Coves
- Artificial Basins
- Nearshore Reef Flats
- Offshore Reef Flats
- Wave-Exposed Reef Communities
- Protected Coral Communities
- Soft Bottom Communities
- Deep Benthos

Lava Rock Shorelines

The islands of Hawaii are of volcanic origin, built up from the sea floor by extrusions of basaltic lava. Where these lava flows meet the sea, like so many basalt coasts throughout the world, steep sea cliffs, horizontal benches or cobbles and boulder beaches may develop. Windward basalt shorelines are usually shaped and dominated by heavy surf and wave action. Striking differences are found in speciation associated with wave-exposed vs. wave sheltered, lava rock shorelines. This is particularly noticeable with the seaweeds, which are often the first to react to changing water quality. (See figures 13 through 20 for maps depicting lava rock shorelines for each of the islands.)

Vertical Shores

Rocky vertical shorelines, sometimes projecting high above sea level and with portions reached only by spray, are inhabited by relatively few species, which are often dull gray or black in color and which can withstand long periods without water. These include the littorines (pupu kolea), among the mollusks and the black grapsid crab, Pachygrapsus pheatus (a'ama). Seaward of the littorines and the crab but still above the reach of the tide are the black nerite (pipipi), Nerita picea and the pulmonate limpet, Siphonaria.

Seaward of the spray zone, at mean tide level, much of the lava coast is colored pink by the alga, Porolithon and studded by the dark, domelike shingle urchin, Colobocentrotus atratus and the opihi, Cellana sandwichensis.

At zero tide level, surf-swept shorelines are inhabited by other rather dark colored and heavy shelled animals, such as Thais and Drupa on the substrate and the brown and white cowries, Cypraea mauritiana and C. maculifera, in crevices. Fishes in these areas are strong swimmers and may be dark in color such as the achilles tang, Acanthurus achilles. Other fishes associated with this area include: the damsel fish Abudefduf imparipennis, the wrasse Thalassoma umbrostigma and the goby Bathygobius cotriceps.

Basalt Benches

Irregular continuous benches of basalt may form horizontal platforms along the shore. Waves play a dominant role in determining the pattern of biotic zonation on these benches with striking differences between windward and leeward coasts.

On windward shores, the highest level of wave action is marked by the red alga, Ahnfeltia, below which there is a variety of frondose algae (Ulva, Sargassum, Grateloupia). Seaward of the algal mat, the substrate is principally the growth form of the encrusting calcareous alga, Porolithon, with Ectocarpus also present. Marking the zero tide level is often the red alga, Pterocladia.

Dominant mollusks seaward of Ahnfeltia are the black foot opihi, Cellana exarata and several smaller gastropods (Siphonaria, Smaragdia, Morula). Porolithon-encrusted areas are dominated by the yellow foot opihi, Cellana sandwicensis and the shingle urchin, Colobocentrotus atratus. The frontal slope of basalt benches may be riddled by the borings of the sea urchin, Echinometra mathaei. Hobson (1974) reported 54 total species of fishes in this habitat off the Kona coast of Hawaii. Some of these include the surgeonfishes, Acanthurus leucopareius and Acanthurus nigrofuscus (herbivores), the wrasses, Thalassoma fuscus and Thalassoma duperreyi (predators) and the damselfishes, Abudefduf imparipennis (predator) and Chromis vanderbilti (planktivore).

Examples of basalt benches occur from Napali to Kapaa and Poipu to Waimea on Kauai; Lanikai to Makapuu and Kaena Point on Oahu; the Hana coast and Cape Kinau on Maui; the north coast of Molokai and along most of the shoreline of the Big Island.

Boulder Beaches

Boulder beaches are formed of large, worn boulders or cobbles of basalt composition. The cobbles and boulders are shaped by marine processes, such as wave scour, currents and other erosive factors, transported and then deposited on beaches by waves and during storms. Example coasts include Kona and Kealakekua on Hawaii, Hana on Maui and Napali on Kauai.

Because of the instability of the substrata and the continual scouring, few organisms inhabit these beaches with the exception of grapsid crabs and a sparse interstitial and under-rock fauna. Hobson (1974) reported 77 species of fish off Kona boulder beaches. The majority of these are herbivorous fish which inhabit these areas grazing on benthis algal turf. They include the surgeonfishes, Acanthurus nigrofuscus and Ctenochaetus strigosus, the yellow tang, Zebrasoma flavescens, the achilles tang, Acanthurus achilles and the wrasse, Thalassoma duperreyi.

Sand Beaches

Hawaiian beach sand is one of the most valuable mineral and recreational resources in the state covering 185 miles of Hawaii's 934 mile shoreline. (See Figures 13 through 20 for maps of sandy beaches on each of the islands.) Three types of sand comprise individual beaches in Hawaii: green (olivine), black basalt (lava) and white (calcium carbonate). Most of Hawaii's beaches are composed of calcareous beach sand which contains the remains of foraminiferans, mollusks, echinoderms, coralline algae and reef corals. Black sand beaches occur on the Big Island and on Maui. Olivine beaches are found on the Big Island and on Oahu.

The calcareous beach sand reservoir varies tremendously from island to island. Kauai, with 1.4×10^7 cubic yards, has the greatest amount, while Hawaii, with 1.7×10^6 cubic yards, has the least. The largest individual beach sand reservoirs exist at Papahako on Molokai, Polihale on Kauai and Polihua on Lanai (Moberly and Chamberlain, 1964).

The beach community is divisible into three zones: 1) an upper zone with terrestrial vegetation and possible dune formation; 2) a mid-beach between the high tide line and the vegetation line and 3) the lower beach which is continually awash by waves.

The benthic animal life found on sand beaches is determined by particle grain size, slope of the beach and color of the sand. The upper beach is characterized by amphipods, isopods and males of the ghost crab (ocypode laevis). Female Ocypode laevis and males of another ghost O. ceratopthalmus, burrow in mid beach areas (Fellows, 1965). The mole crab, Hippa pacifica, spinoid polychaetes and the mollusk Terebra spp. occur in low beach areas. The coloration of these animals usually blends cryptically into that of their environment.

Fishes which generally associate with sandy beach areas include the thredfin, Polydactylus sexfilis; the goatfishes, Upeneus arge and Mulloidicthys samoensis; the bonefish, Albula vulpes; the trichonotid, Crystallodytes cookei and the burrowing eel, Caecula platyrhyncha.

Beaches continually change, at one time eroding, at other times accreting. Much of this variation is directly associated with the amount of wave energy that affects the beaches on a seasonal basis. Beaches with a western exposure, for example, begin to erode during winter months due to high Kona waves. During the summer, these western beaches accrete because of northeasterly winds and waves (Moberly and Chamberlain, 1964). Beaches on the windward sides of the Hawaiian Islands, however, accrete when the northeast trades diminish and erode during heavy northeast trade swells or North Pacific swells.

Non-climactic factors may also yield changes in beach size. For example, the construction of man-made breakwaters, jetties and groins results in the modification of circulation and current patterns potentially causing the erosion and accretion of sand beaches, the deposition of silt in harbor basins and the resultant reduction and/or elimination of certain biota and their replacement by forms more tolerant of the changed environment.

Solution Benches

The prime requisite for the appearance of a solution bench is a consolidated limestone coast. Fifty-two miles or about 31 percent of Oahu's coastline are comprised of this type (Wentworth, 1972). (See Figures 13 through 20 for maps identifying solution benches.) In Hawaii, the two main types include those from limestone composed chiefly of reef coral and calcareous algae and those formed from detrital limestone, composed of sand and graval containing calcareous skeletons of various organisms. The solution bench is more typically and extensively developed on the reef limestone or carbonate. These solution benches, or sea level platforms, may extend from 1 to 30 meters seaward from the shoreline.

On Oahu, nearly continuous stretches of solution bench occur on the Waianae coast, east of Kaena Point on the north coast, near Waimea Bay, around Kahuku Point and on parts of the Mokapu Peninsula. Both windward and leeward coasts may contain solution benches which are developed from the exposure of limestone to both continual wash by sea water and periodic solution by rain water.

Two major characteristics of the solution bench are the bench and the nip. The bench commences at the seaward margin and rises fairly steeply from the ocean. Its inland margin is characterized by a pitted zone. The nip is a marked notch which undercuts the limestone shore at one to three feet above sea level.

Solution benches are distinguished by a cover of thick algal turf (*Padina*, *Acanthophora*, *Chroospora*) and by conspicuous zonation of flora and fauna. Calcareous algae are concentrated at the sloping outer edge, where corals are sometimes present. Most information on biota is confined to the mollusks. Various assemblages of grazing herbivorous mollusks (*Cypraea caputserpentis*, *Haminoea aperta*) are found within the algal growth as well as mats of filter feeding mollusks (*Brachidontes crebristriatus*, *Dendropoma gregaria*) and active carnivorous snails (cones, miters). The dominant micromollusks are the herbivores, especially Barleea and Rissoella which are associated with the algae on the benches. The pools of the pitted zone contain the small littorine snail Peasiella tanitella. On the bench appear the cone snails, with Conus abbreviatus nearest shore and Conus chaldaeus nearest the seaward edge.

Fishes occurring here are usually similar to those found in rocky tidepool areas and include young damselfish, Abudefduf sordidus and the blennies, Entomacrodus marmoratus and Istiblennius zebra.

Marine Pools and Protected Coves

Marine tidepools can be formed by depressions in sea level basalt outcrops or solution benches or by massive boulders fronting the sea. (See Figures 13 through 20 for maps identifying marine pools throughout the islands.) They can be extremely shallow or quite deep. Physical conditions of temperature, salinity and pH vary with exposure and with distance from the sea. Sub-surface connections to the sea are common, subjecting the pools to tidal fluctuations. The biota includes small mollusks, worms, occasional grapsid crabs, the blenniid fishes, Istiblennius zebra and Entomacrodus marmoratus and the gobiid fishes, Bathygobius fuscus and Kelloggella oligolepis.

Some marine pools exposed to fresh-water runoff or rain develop a type of thermocline below which the temperature may rise considerably. There may be great seasonal differences in biota, both above and below such thermoclines. On Rabbit Island and the south shore of Moku Manu, some pools are densely inhabited by the alga Enteromorpha at their bottoms only.

The larger the pools, the more uniform are the conditions, especially with a large volume in relation to the surface area. In some of these larger pools and in the smaller ones at high tide, they become hydrologically quite similar to the sea. These pools, particularly if they are large, provide suitable habitat for a variety of reef corals and tend to become havens for displaced deeper forms or for juvenile fish such as Acanthurus sandvicensis (manini), Kuhlia sandvicensis (aholehole), Chaetodon lunula and Abudefduf sordidus. Some examples of these larger tidepool systems include Wailua Bay, Kiholo, Hilo, Honaunau, Kapoho and King's Landing on Hawaii, Hanamaulu on Kauai and the south coast of Molokai.

Marine pools of an artificial sort are the fish ponds of Hawaii. Although most have deteriorated considerably from ancient Hawaiian times because of disuse or misuse, many are still functioning for aquacultural purposes or have potential for restoration.

Protected coves which are removed from heavy wave or surge action are found along the Keaukaha side of Hilo Bay, at Punaluu and at Halape.

Resident biota resembles that found in marine pools such as the algae Jania and Rhizoclonium.

Artificial Basins

(See Figures 13 through 20 for maps depicting artificial basins for each of the islands.) The influence of dredging, man-made structures and other human activities will have profound effects on the natural ecosystems of an area. A common example of this is an altered community following the transformation of a natural embayment, coastline or estuary into a boat harbor. Honolulu Harbor is by far the largest commercial deepwater facility in Hawaii. Known originally as Kapalama estuary, it is fed by Nuuanu Stream, including its major tributary Pauoa Stream, as well as from Kapalama Canal. Originally, a natural channel in the reef, resulting from this freshwater input, restricted the growth of corals and allowed for the enlarging of the size of the harbor in the mid-1800's. Now, much reef has been destroyed and nearby lowland areas have been filled with dredged materials and sediment from natural runoff.

Other commercial deepwater harbors include Hilo and Kawaihae on the Big Island, Kahului on Maui and Nawiliwili and Port Allen on Kauai. Their shelter makes these waters desirable for a number of recreational as well as commercial uses. Consequently, conflict has arisen regarding optimum use of these waters.

Small boat harbors are found on all of the islands and have only some characteristics in common with the larger harbors. Flushing action within the smaller harbors is generally better with resultant coarser bottom sediments. They are not as deep and light can generally penetrate to these bottom sediments. Small boat harbors have been built along and sometimes out beyond natural coastline features. Some representative small boat harbors include Maalaea and Lahaina on Maui, Honokohau on the Big Island, Nawiliwili on Kauai, Kaunakakai on Molokai, Manele on Lanai and Pokai Bay, Ala Wai, Kewalo and Haleiwa on Oahu.

Both the quantity and quality of the fresh water input to many artificial basins and harbors varies considerably. Perennial streams may drain through agricultural lands as well as through highly urbanized areas near the harbors. Groundwater seepage and artesian wells also contribute to this freshwater input. Although the "natural pollution" carried by this freshwater supply is long standing, it does not compare to pollution resulting from urban and industrial sewage disposal, accelerated sedimentation, sugar mill waste-water discharges, ship discharges, cesspool seepage and thermal effluent which cumulatively act in fouling the harbor waters and altering the original ecosystem.

Water depths vary among harbors and within the same harbor from 2 to 15 m. Those harbors projecting out from the natural shoreline are characterized by moles, revetments, breakwaters, rip rap and other protective structures. Quarried harbors show a greater preponderance of vertical rocky walls. Most harbors contain wharves, docks, piles, piers, buoys, slips and other facilities and structures. The abundance and diversity of these structures can provide a variety of substrate habitats for coralline and frondose algae, fouling organisms such as *Teredo*, rock crabs (grapsids and others), the Hawaiian oyster, *Ostrea sandvicensis*, barnacles and several reef corals (*Pocillopora*, *Porites*, *Cyphastrea*, *Pavona* and *Montipora*). In addition, several schooling fishes such as iao, nehu, omaka, aholehole and mullet, migrate from surrounding environments.

Nearshore Reef Flats

Hawaiian nearshore reef flats are shallow platforms which hug the shorelines of high islands at water depths of 0 to 3 m. (See Figures 13 through 20 for maps depicting nearshore reef flats for each of the islands.) They are composed of reef rock derived from the skeletons of a variety of reef dwelling marine organisms. Crustose coralline algae and reef corals contribute the bulk of material to the reef framework but the skeletons or fragments of mollusks (primarily gastropods), foraminiferans, echinoderms (sea urchins, sea cucumbers, sea stars) and sand producing algae may also contribute mass to the reef, principally as sediment. Coralline algae are the principal agents cementing all of these components together forming consolidated reef rock. Prominent geological surface features on reef flats include reef blocks, coral rubble and sand patches.

Nearshore reef flats include both apron and fringing reef types. The former represents an earlier stage in reef growth leading to the latter. Apron reefs are smaller and project out from the shoreline as semi-circular aprons while fringing reefs are more extensive and form wide continuous flats parallel to the coastline for long distances.

A great variety of marine life occurs on nearshore reef flats including frondose, filamentous and coralline algae of many species (particularly *Acanthophora*, *Sargassum* and *Porolithon*). Benthic algae usually dominate surface coverage on flats. Several forms of reef coral also are common components, particularly near the outer edges of flats.

The number of fish species is generally lower than in other reef areas and the following is a list of fishes which frequent nearshore reef flats.

Scientific name	Common name	Hawaiian name	Feeding habits
Acanthurus nigrofuscus	surgeonfish	maiii	herbivore
Thalassoma duperreyi	wrasse	hinalea	diurnal predator
Abudefduf imparipennis	damselfish		diurnal predator
Chromis vanderbilti	damselfish		diurnal planktivore
Thalassoma fuscus	wrasse	awela, hou	diurnal predator
Apogon menesemus	cardinal fish	upapalu	nocturnal predator

A variety of invertebrates also inhabit reef flats. Beneath the reef flat surface are found a myriad of mollusks, echinoderms, polychaetes, sipunculids, other worms, crustaceans and boring algae within the cavernous framework of solid reef, while infaunal mollusks (Conus, Terebra and others) and annelid worms live buried in sand deposits.

The growth and maintenance of reef flats is an uneasy balance between biologically constructive forces (carbonate secreting organisms) and physically destructive forces (scour, wave action and currents). Organisms occupying shallow reef flats normally cannot tolerate the extreme conditions associated with tidal, salinity, wave and temperature fluctuations occurring at the sea surface and as a consequence, few reef flats grow to sea level and emerge at low tide. Thus growth of the reef and extension of the reef flat occurs primarily in a horizontal direction, away from the shore, once the upward limit of growth is attained. The water depth or level of a reef flat in any particular location depends partially upon the severity of growth-inhibiting factors. For example, flats on the windward sides of islands subjected to heavy wave action, freshwater runoff and natural sedimentation are unlikely to grow as vigorously because reef-building organisms may find these environments suboptimal. Conversely, reef flats may grow at very shallow water depths where conditions are more favorable. The activities of men onshore may upset the balance of the constructive and destructive forces changing the composition and structure of reef flat habitats; sedimentation from soil erosion, excessive flooding, sewage discharge and thermal pollution have been identified as adverse impacts.

Nearshore reef flats are common on Kauai's northeast coast and also present on the south and southeast coasts. Oahu's shorelines harbor extensive fringing reef flats along the windward (NE) and southern coasts with scattered apron reef flats along the north shore. Prehistoric uplifted reefs also form much of the existing land along the southern Honolulu plain and Kahuku. Virtually, the entire south coast of Molokai is fringed by a wide flourishing reef, perhaps the best developed among the high islands of the State and a small apron reef is located on the leeward (W) side of Kalaupapa peninsula. A wide and well developed fringing reef is found along the entire northeast coast of Lanai. In contrast, Maui has only a few apron reef flats which are confined to Lahaina, Kahului, Kihei and Makena regions. Only a single small apron reef is reported from the island of Hawaii near Kawaihae-Puako. The lack of reefs and reef flats on Maui and Hawaii may be attributed to the geological instability and young age of the islands. Niihau and Kahoolawe lack reef flats altogether.

Nearshore reef flats serve many important functions and uses including: habitat for many subsistence and recreational fishery resources (including octopus, shellfish, lobster, crabs, limu and finfish); ideal conditions for surfing and boating; natural breakwaters protecting life and property from storm waves and tsunamis; sources of sand to replenish all white sand beaches; ideal swimming, diving and snorkeling conditions; aesthetics; and opportunities for scientific and medicinal research. Nearshore reef flats are also subjected to a number of consumptive uses including: mining for sand and aggregate materials for the construction industry; the sites for harbor basins and channels; the collection or harvesting of fishes, corals and shells for consumptive and commercial purposes and receiving waters for wastewater discharge.

Offshore Reef Flats

Offshore reef flats are shallow submerged platforms, or shoals, of reef carbonate occurring at water depths of 0 to 3 m and separated from the shoreline of high islands by wide deep lagoons or ocean expanses. (See Figures 13 through 20 for maps depicting offshore reef flat areas.) Crustose, coralline algae, frondose algae, scoured reef rock, and live encrusting or robust corals predominate on the outer or seaward, facing sections of offshore reef flats; while sand and gravel deposits, scattered microatolls (pancake shaped corals), mollusk communities and extensive patches of benthic algae are conspicuous on the inner and usually shallower portions of these flats. Sand cays and low coral islands may be found on some offshore flats.

Normally, heavy wave action on the seaward side of the reef flat drives uni-directional water currents across the reef, contributing much to the biological and geological zonation characterizing offshore reef flats.

The presence of heavier wave action, water of more oceanic character and the absence of terrigenous influences (i.e., sediment, rainfall, runoff) from high islands distinguish the offshore reef flats from nearshore flats for water quality management purposes.

In Hawaii, there are three types of offshore reef flats--patch, barrier and atoll reef flats. Although quite different from one another structurally, they all share the common significant factor of being separated from populous and stressed high island marine environments. As a consequence, the offshore reef flats are subjected to fewer perturbations by man.

Patch reefs are reported only from the lagoon of Kaneohe Bay, Oahu, among the high islands of the Hawaiian chain but are common within the lagoons of some of the atolls at the northwest end of the archipelago. The Kaneohe patch reefs structurally consist of the remains of reef corals, principally finger coral (Porites compressa). They assume the shape of truncated cones with the shallow reef flats exhibiting a circular outline. The reefs are up to 20 m in height and 1000 m wide, although they are usually of smaller dimensions. The tops of the reef flats are covered with gravel and sand deposits, calcareous or frondose algae (Porolithon and Sargassum), and isolated scattered coral heads. Live coral coverage becomes more predominant along outer edges of the reef flats; fingercoral (Porites), tree coral (Pocillopora), plate coral (Montipora) and mushroom coral (Fungia) are most conspicuous.

A tremendous variety of reef fish inhabit patch reef flats, particularly near the outer edge. The work of Gerald Key (1973) identifies common fish species of Kaneohe Bay. The most common species observed in patch reef areas, in decreasing order of abundance, are:

Scientific name	Common name	Hawaiian name	Feeding habits
Scarus spp.	parrotfish	uhu	diurnal herbivore
Pranesus insularum	silverside	iao	nocturnal planktivore
Thallasoma dupperreyi	saddleback wrasse	hinalea	diurnal predator
Dascyllus albesella	damselfish		diurnal planktivore
Zebrasoma flavescens	yellow tang	pala	herbivore
Gomphosus varius	bird wrasse		diurnal predator
Chaetodon miliaris	lemon butter fish		diurnal planktivore
Pomocentrus jenkinsi	damselfish	mamo	diurnal omnivore
Ctenochaetus strigosus	surgeonfish	kole	herbivore
Labroides phthirophagus	cleaner wrasse		cleans ectoparasites
Stethojulis axillaris	wrasse		diurnal predator
Abudefduf abdominalis	damselfish	maomao	diurnal planktivore

Larval fish species found in the lee of Kaneohe Bay reefs (Miller, 1973) are those with demersal eggs, usually attached to hard substrate. Included among these are the Blenniidae, Gobiidae, Pomacentridae, Hemirhamphidae and Belonidae. Species whose larvae are taken from tidal channels between reefs typically have pelagic eggs--the adults also being found primarily in open ocean pelagic water.

The second type of offshore reef flat type is the barrier reef and the only example from the Hawaiian Islands occurs offshore from Kaneohe Bay. The reef is large, measuring 2 km by 5 km and is 2 km from the shoreline of Oahu. Large sand channels are found at each end of the reef. The reef is structurally complex and is composed of lithified dune rock, beach rock, reef rock and thick sand deposits. The ocean edge exhibits greater abundance of reef-building organisms and the zone of maximum wave exposure is heavily scoured. Fields of frondose algae and microatolls interspersed with microatolls of *Porites* and *Montipora* are predominant features along the inner lagoon flats. Unique sand mollusk communities (*Terebra* spp.) and sea cucumber populations (*Holothuria atra*, *Ophiodesoma*) are also found near the lagoon edge.

The most commonly observed fishes in the Kaneohe barrier reef area, in decreasing order of abundance, are:

Scientific name	Common name	Hawaiian name	Feeding habits
Scarus spp.	parrotfish	uhu	diurnal herbivore
Acanthurus sandvicensis	convict tang	manini	diurnal herbivore
Stethojulis axillaris	wrasse		diurnal predator
Mullodicthys samoensis	goatfish	weke	predator on sand dwelling inverts
Thallosoma duperreyi	saddleback wrasse	hinalea	diurnal predator
Dascyllus albesella	damselfish		diurnal planktivore
Abudefduf abdominalis	damselfish	maomao	diurnal planktivore
Paraupeneus porphyreus	goatfish	kumu	nocturnal predator

Atoll reefs represent the third type of offshore reef flats and are confined to the northwest end of the Hawaiian island chain, well removed from population centers. Only Midway, Kure and Pearl-and-Hermes Reef have been studied and information about Hawaiian atoll reefs in general is sketchy. Typically, atoll reefs are raised "rings" which partially or wholly enclose a lagoon of 3 m or more in depth. Shallow to deep sand channels and rocky passes bisect the reef rim and coral islands may be situated atop the reef flats, formed during tropical storms when large waves cast reef debris onto the flats. Little is known of the biological composition of Hawaiian atoll reef flats. Atoll reefs represent the most advanced stage of reef development and it is generally thought that most atoll reefs have evolved from earlier fringing and barrier reef stages.

Generally, offshore reef flats are important habitats for migratory birds and sea birds, some of which are rare and are feeding and nesting grounds for sea turtles including some which are proposed threatened species. Offshore reefs are valuable to man in providing education, recreation and scientific research opportunities. Consumptive uses also include establishing island installations for navigation and weather facilities and commercial fishing operations.

Wave Exposed Reef Communities

Wave exposed reef communities are the most extensive shallow marine habitats in Hawaii and are subjected to heavy or continuous coastal wave action. These communities begin beyond the shoreline, if shallow reef flats are absent or beyond the outer edge of nearshore or offshore reef flats. The communities span depths of 0 to 40 m and overlie irregular solid substrata, the latter sometimes sloping gradually to deeper water often with several ledges and terraces. The hard substratum is composed of basalt or carbonate rock but sand channels and depressions are also conspicuous features.

Wave exposed reef communities can be separated into shallower (0 to 10 m) and deeper zones (10 to 40 m) on the basis of biological differences and changes in the intensity of controlling forces such as wave action, surge, light penetration, sediment transport and other factors. The severity of the wave action usually dictates the degree of community development. Where wave action is low, coral and algal cover is higher and the communities flourishing, sometimes approaching protected coral communities in ecological complexity. Where wave action is excessive, scour, mechanical stress and shifting sand inhibit biological development and the habitat appears generally barren but with extensive crustose coralline algal growth.

The substratum of the shallow zone is dominated by crustose coralline algae (*Porolithon* spp. and others), turf algae and filamentous algae of many varieties. The coralline forms cement rock fragments together to maintain the rigid substratum, while the other algae serve as food for many invertebrates and fishes.

Reef corals are invariably present and are most important in maintaining relief and habitat for the community and contributing to the accretion of the substratum but corals are not the dominant bottom organisms in terms of surface coverage. The rose coral *Pocillopora meandrina* and encrustations or small heads of the coral *Porites lobata* collectively account for more live coral cover than all other coral species combined. Other conspicuous invertebrates include the reef corals *Montipora* spp., *Pavona* spp., *Leptastrea*, the soft coral *Palythoa*, the sea urchin *Echinothrix*, the sea cucumbers *Actinopyga* and *Holothuria* spp. A variety of mollusks also occupy shallower areas in the habitat.

Fish species on the shallow reef include:

Scientific name	Common name	Hawaiian name	Feeding habits
Chromis vanderbilti	damselfish		diurnal planktivore
Ctenochaetus strigosus	surgeonfish	kole	herbivore
Zebrasoma flavescens	yellow tang	pala	herbivore
Acanthurus leucopareius	surgeonfish	maikoiko	herbivore
Acanthurus nigrofuscus	surgeonfish	maiii	herbivore

The deep zone is also dominated by benthic algae, but sand deposits and channels may be more conspicuous and coral coverage slightly higher, particularly Porites lobata, due to reductions in scour and surge currents. Other deep corals include Pocillopora spp., Porites compressa and Montipora. Other common invertebrates include the green sea star Linckia, the crown-of-thorns starfish Acanthaster planci, the wana or black sea urchin Diadema paucispinum, the sea urchin Echinothrix, the heart urchin Tripneustes gratilla and sometimes the sea cucumber, Stichopus. Fish species include:

Scientific name	Common name	Hawaiian name	Feeding habits
Naso hexacanthus	surgeonfish	kala	diurnal planktivore
Chromis leucurus	damselfish		diurnal planktivore
Xanthichthys ringens	triggerfish		diurnal planktivore
Thalassoma duperreyi	wrasse	hinalea	diurnal predator
Zebrasoma flavescens	yellow tang	pala	herbivore

The wave exposed reef community habitat represents the zone where much of the active growth of shallow reefs is supposed to be taking place, counteracting the destructive forces of wave action and abrasion. However, some scientists do not believe that Hawaiian reefs in wave exposed environments are growing or even maintaining equilibrium. It is difficult to believe that many of the wide fringing reefs, particularly along windward coasts, could be growing under present conditions, as evidenced by the lack of development of the reef communities reported on many outer reef slopes. Present rigorous climatic conditions and perhaps water quality degradation may explain the apparent eroding or poor condition of some reef communities. There is, however, no question that the survival and growth of wave exposed reef communities is in uncertain balance with destructive natural forces. Additional disruptive environmental impacts, whether man induced or natural, can easily shift the dynamics of the systems to a more adverse posture.

Studies of the growth of reefs on submarine lava flows which have entered the ocean off the coast of the island of Hawaii during known historical times indicate the wave exposed communities may take 15 to 40 years to develop and reach maturity. Thus, it is assumed that damage or destroyed reef habitats would also take a protracted and comparable time to recover if adverse environmental factors are first eliminated. This is all the more reason to manage and protect these resources in a responsible manner.

Wave exposed coral communities are extremely important in offering food and shelter to a variety of recreational and commercial fishery resources. These systems also contribute significantly to replenishment of white sand beaches in the state. High underwater visibility renders these reef habitats excellent for diving, swimming and snorkeling. Many fishes for the aquarium trade are collected here.

The excellent water flushing and current characteristics in many locations where wave exposed reef communities exist provide some opportunities for disposal of moderate or small quantities of treated wastewater and other pollutants without significant adverse environmental effects. This is not possible in shallow coastal environments where flushing and circulation conditions are not as favorable.

Protected Coral Communities

Protected coral communities are found at water depths between 0 and 40 m but are best developed at depths of 10 to 30 m along favorable open coast environments or in shallower water in sheltered embayments. (See Figures 13 through 20 for maps of these areas.) Along open coasts, these communities are removed from heavy or continuous wave action by being confined to deeper water below the wave base (at approximately 10 m depth). They are found particularly along leeward coasts where tradewind wave energy is reduced. Elsewhere, protected coral communities are confined to lagoon environments behind atoll or barrier reefs or within the calm reaches of bays or coves.

The bottom surface is dominated by live coral which covers up to 50% or more of the bottom. Sand channels and patches are also occasionally scattered in depressions or valleys between coral thickets, mounds or platforms. Thick extensive sand deposits usually form the deep offshore boundaries of the habitat.

The sand within this habitat is produced from the breakdown of coral and skeletons of other carbonate secreting organisms. Protected coral communities can perpetuate themselves only where sand production and accumulation does not exceed the capacity of the corals to grow and avoid burial. Moderate to gentle slopes offer ideal conditions for these communities because sand, which is constantly produced, can be transported downslope away from the habitat.

The fingercoral, *Porites compressa*, is usually among the most dominant of the corals in this habitat, particularly in its most protected portions. Fingercoral forms continuous platforms or thickets up to many meters across and provides a micro-habitat for a variety of invertebrates and small fishes. Almost pure stands of fingercoral grow in Kaneohe Bay and deeper ocean slopes off the Kona coast of Hawaii island.

Porites lobata is also a common coral in the community and forms large mounds or pinnacles scattered among the fingercoral. Larger fishes tend to associate with *Porites lobata* because of the greater relief and larger shelters it can provide. The abundance of *P. lobata* ranges from very low to dominance (greater abundance than fingercoral). Almost pure stands of *P. lobata* are found in shallower water off Lahaina, Makena (Maui) and the Kona coast, Hawaii, and the coral becomes more common where wave energy increases. Excellent examples of mixed Porites communities occur at intermediate depths off the Kona coast and Kahe, Oahu.

Occasionally, a third coral Montipora verrucosa becomes common (such as in Kaneohe Bay) or dominant (such as off south Molokai) in protected coral communities and appears to favor waters slightly diluted by freshwater intrusions or runoff from land. At times, leafy forms of the coral Pavona grow around the bases of fingercoral or the mushroom coral Fungia aggregates in small depressions.

Other common invertebrates include the slate pencil urchins Heterocentrotus and Chondreocidaris, the heart urchin Tripneustes, the sea urchins Echinothrix spp. and mollusks of many varieties including the cowries (Cypraea). The soft coral Anthelia edmondsoni occasionally is reported growing on dead coral, while filamentous algae, crustose coralline algae, bryozoans and sponges are seen on rocky surfaces.

Protected coral communities also harbor the greatest abundance and diversity of reef fishes including:

Scientific name	Common name	Hawaiian name	Feeding habits
Ctenochaetus strigosus	surgeonfish	kole	herbivore
Chromis leucurus	damselfish		diurnal planktivore
Zebrasoma flavescens	yellow tang	pala	herbivore
Pomacentrus jenkinsi	damselfish	mamo	diurnal omnivore
Thalassoma duperreyi	wrasse	hinalea	diurnal predator
Chaetodon multicinctus	pebbled butterfly	kikakapu	diurnal predator
Acanthurus nigroris	surgeonfish	maiko	herbivore
Myripristis argyromus	menpachi	u'u	nocturnal predator

The best developed coral communities are normally associated with the clearest of ocean waters with underwater visibility approaching 50 m or more and are extremely sensitive to waste water discharges, sedimentation and severe freshwater flooding.

Where these communities occur in shallow water, they commonly form the actively growing faces of flourishing reefs, such as reported in northern Kaneohe Bay and off most of the southern coast of Molokai. The communities require 30 or more years to reach maturity based upon coral colonization studies on lava flows off Hawaii island.

Aside from areas already mentioned, protected coral communities are also found along the entire Kona coast of Hawaii; Honolua, Fleming, Ahihi, Puu Olae, Maalaea and La Perouse Bay on Maui; Molokini Island; Manele Bay on Lanai and Kahana, Waikiki and Hanauma Bay on Oahu. Information is sketchy for the islands of Niihau, Kauai, Kahoolawe and most of Lanai.

Protected coral communities offer the best recreational diving sites in Hawaii, where aesthetics, fish, shells, underwater photography and scientific research are avidly pursued. However, they are much less commonly distributed than wave exposed reef communities and require greater protection and more comprehensive management.

Soft Bottom Communities

Very little information is known about offshore sediments. The waters are too deep for observation except under the most ideal conditions when some outlines of sandy and non-sandy bottoms can be seen. To our knowledge, the inventory of the leeward coast of Maui and Molokai (Campbell et al., 1971) as well as the offshore inventory for Oahu (Moberly et al., 1975) are the only documents available.

Sediments range from large particle sand grains (.062mm - 2mm) to the amorphous silt grain sizes (finer than .062mm). These sediments may retain and slowly leak pollutants into the water column after the water lying above these sediments has been freed of the pollutant. Consequently, offshore sediments, although currently poorly described, may in fact be one of the more important water quality indicators we have.

The variety of infaunal invertebrates is poor in Hawaii compared to the continental soft bottom habitats. The most characteristic creatures are the mollusks Terebra, Pinna and Tapes.

Deep Benthos

The deep benthos refers to a relatively poorly described but extensive area below approximately 40 meters. Although a poorly described area owing to its relative inaccessability, the deep benthos is frequently utilized for ocean disposal. The Hawaiian islands lack a true transitional shelf and great depths are reached at relatively short distances from the shoreline. At these depths, coral reef communities are no longer capable of flourishing, water movement is greatly reduced and the deeper forms of animal life begin to appear.

Much information on a deep benthic biota is confined to commercial or recreational species. Precious corals such as the black corals Cirripathes and Antipathes, the gold coral and the pink coral Corallium are found here. These precious corals, a variety of non-reef building corals (ahermatypes) and the bivalve Pinna maintain themselves on falling detrital material. Crustacea, such as the Kona crab, adult haole crabs, and the shrimps Penaeus marginatus and Heterocarpus ensifer, and demersal fish species, including the grouper

Epinephelus quernus (Hapuupuu), the pink snapper Pristopomoides microlepis (opakapaka), the red snapper Etelis carbunculus (onaga) and the yellowtail Seriola dumerilii (kahala) are either commercially fished now or have commercial potential.

Information Relating to Maps

of Shoreline and Offshore Physical Characteristics

SHORELINE PHYSICAL CHARACTERISTICS

Sand

Lava Rock

Artificial Structures

OFFSHORE PHYSICAL CHARACTERISTICS

Protected Coral Communities

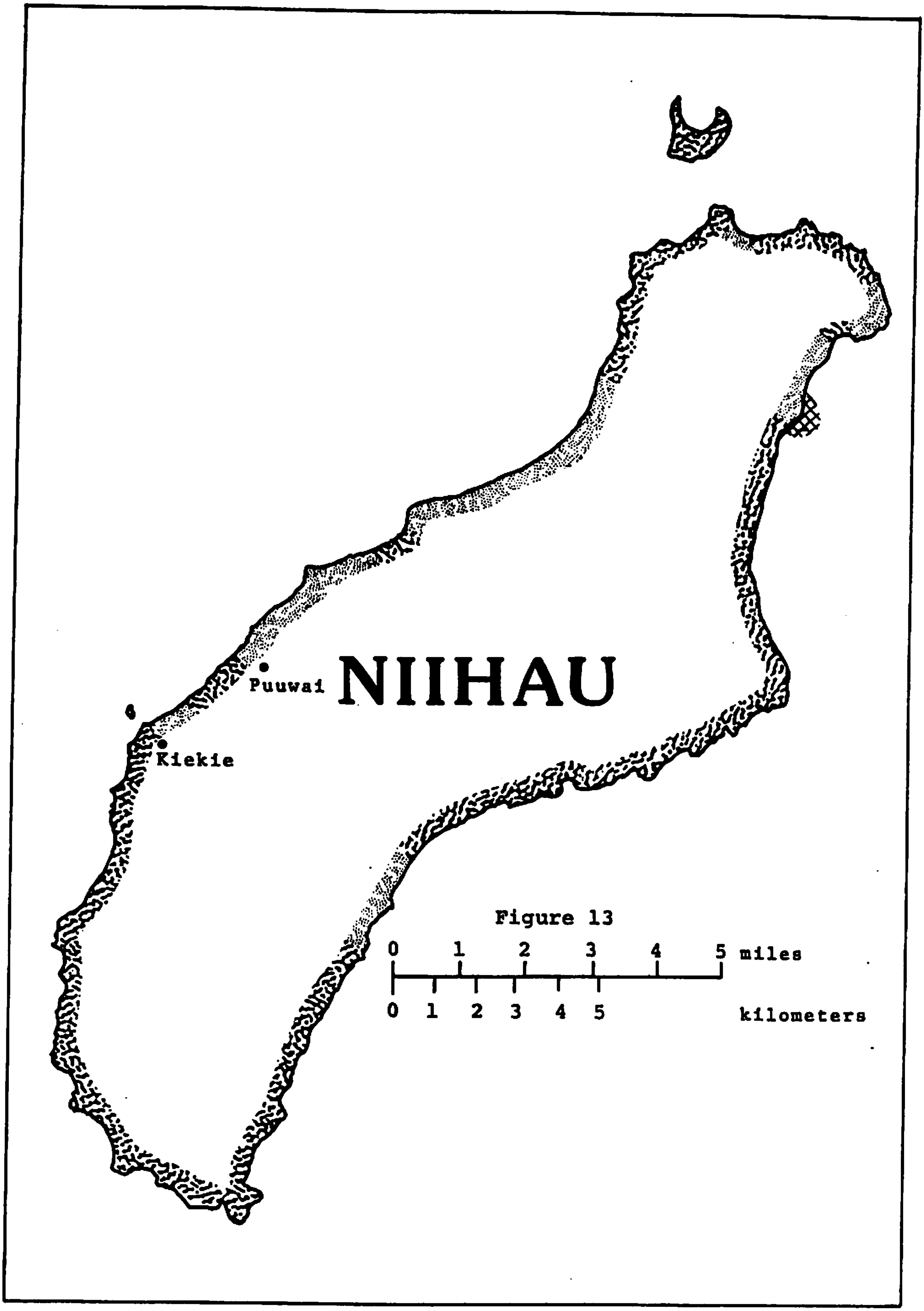
Nearshore Reef Flat

Offshore Reef Flat

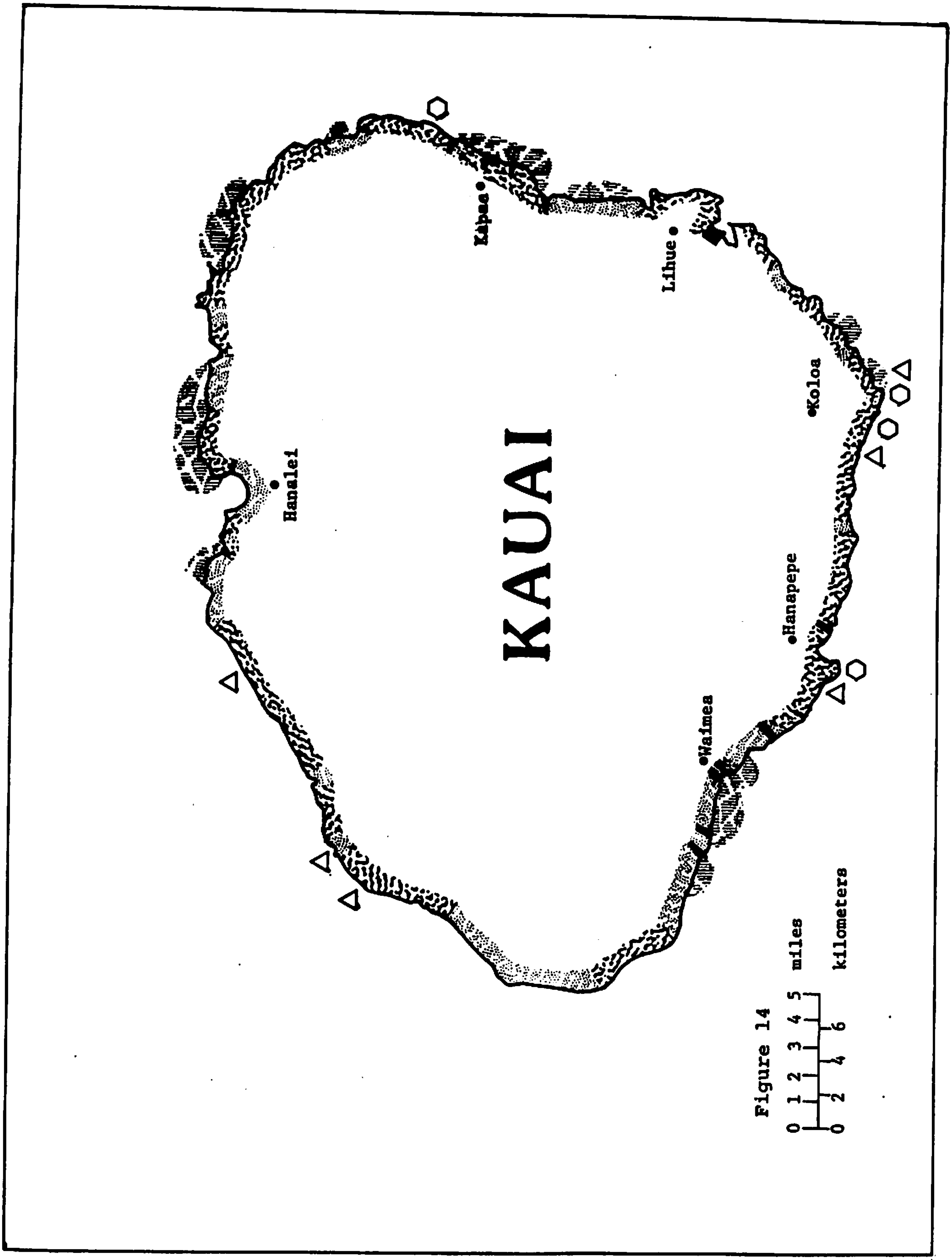
Tide Pools

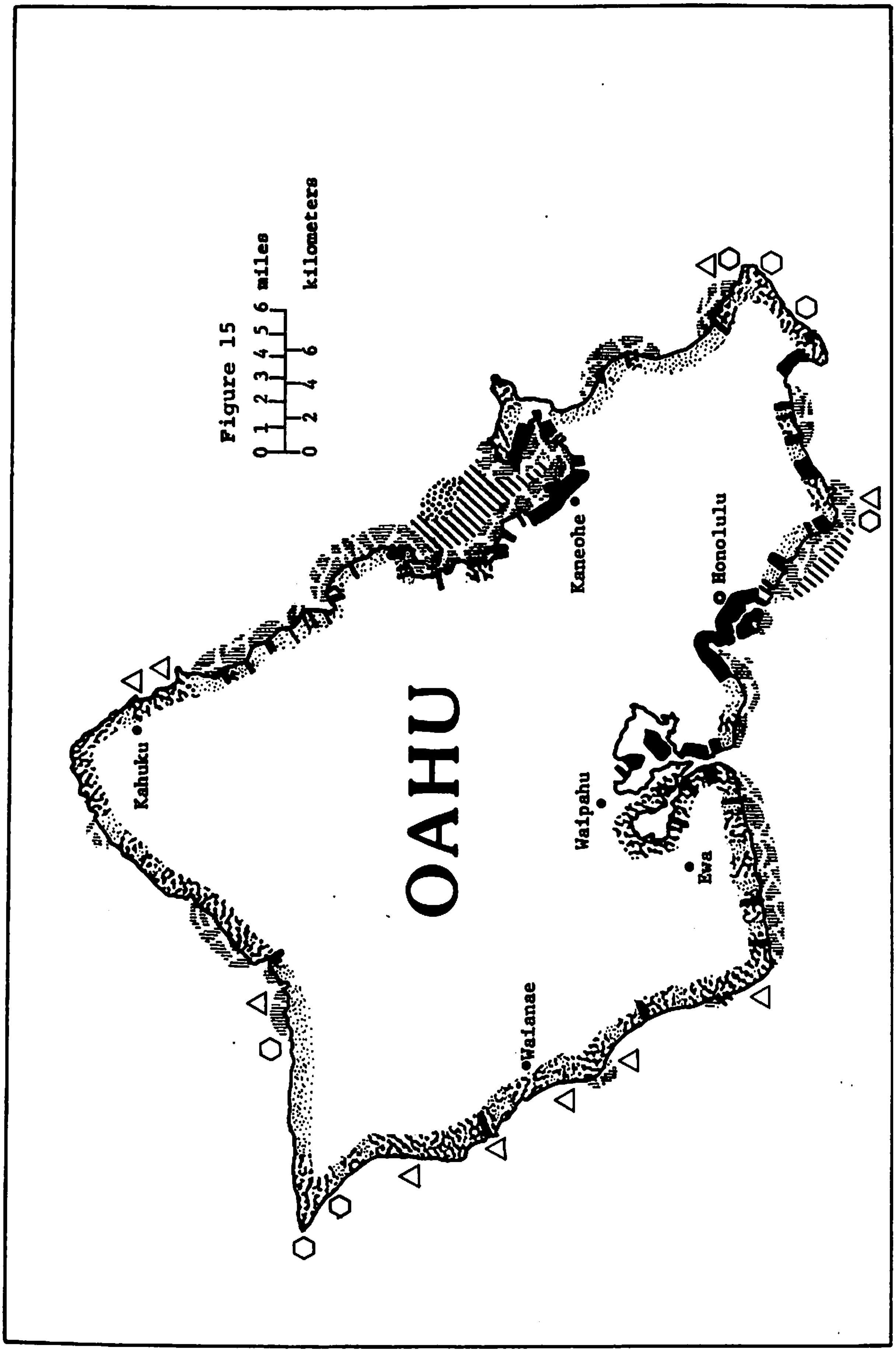
Solution Benches

Wave Exposed Reef Communities


NIIHAU
Puuwai
Kiekie
Figure 13
0 1 2 3 4 5 miles
0 1 2 3 4 5 kilometers

S-09-367


KAUAI
Hanalei
Kapaa
Lihue
Koloa
Hanapepe
Waimea
0 1 2 3 4 5 miles
0 2 4 6 kilometers
Figure 14


0 1 2 3 4 5 6 miles
0 2 4 6 kilometers
OAHU
Kahuku
Kaneohe
Honolulu
Waipahu
Ewa
Waianae
Figure 15

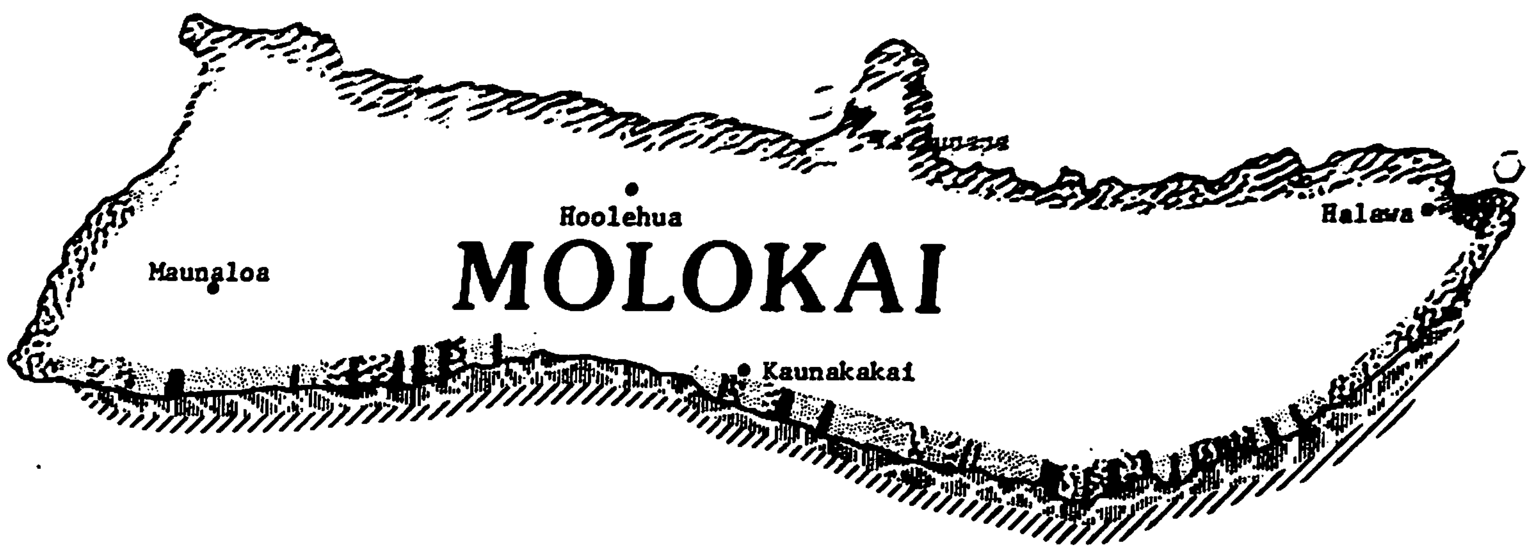


Figure 16

0 1 2 3 4 5 miles

0 2 4 6 kilometers

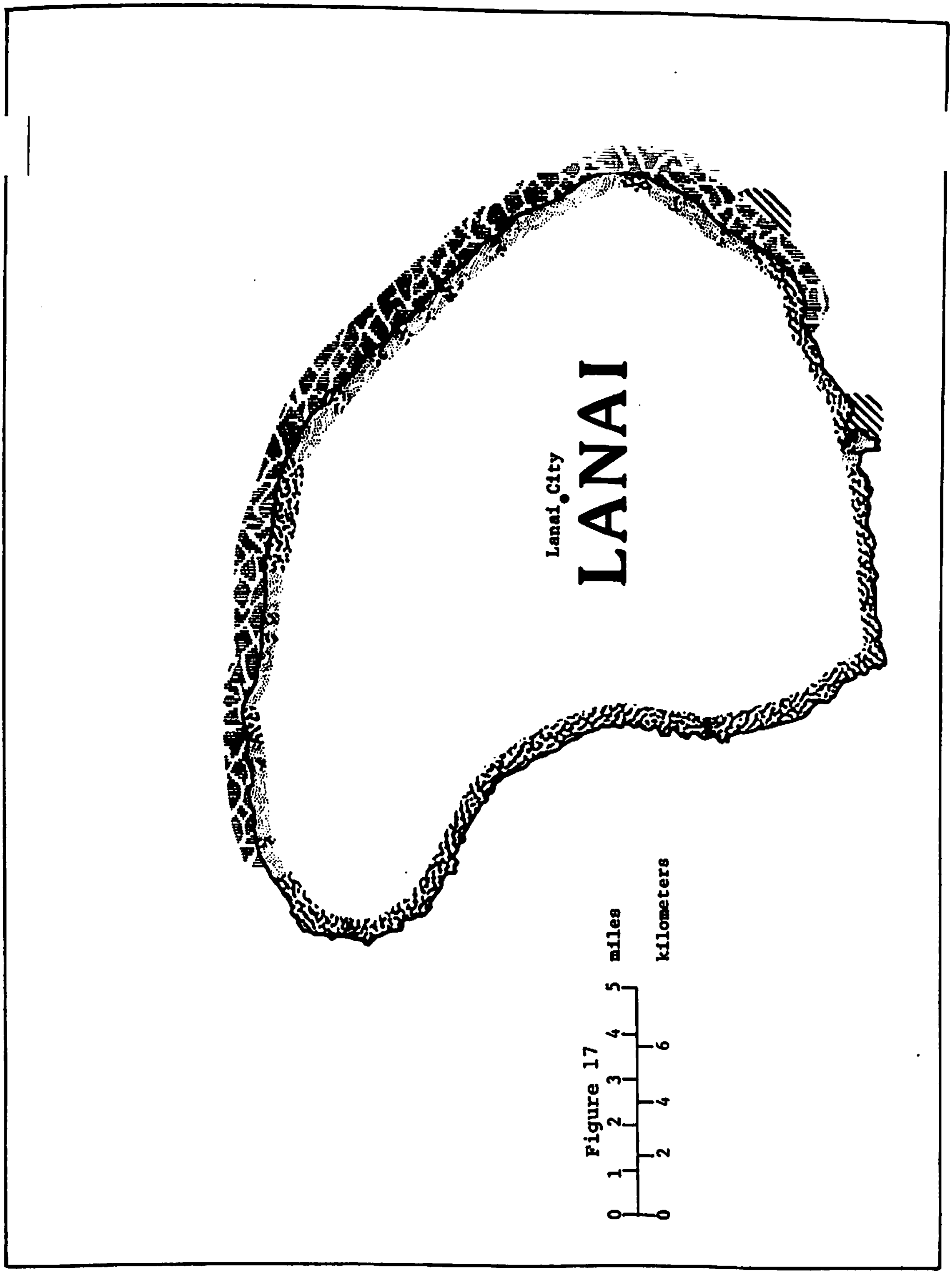


Figure 17

S-09-371

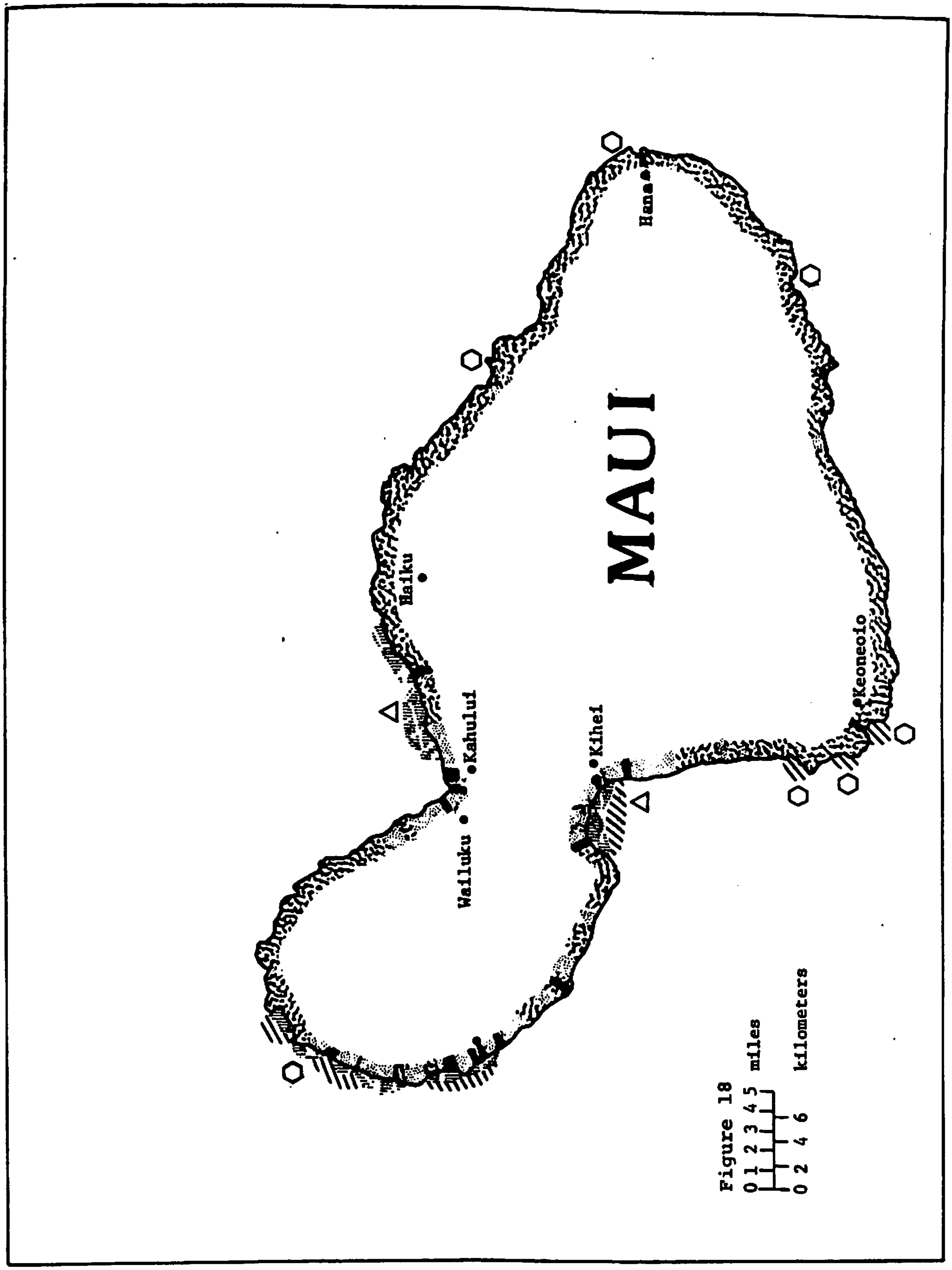
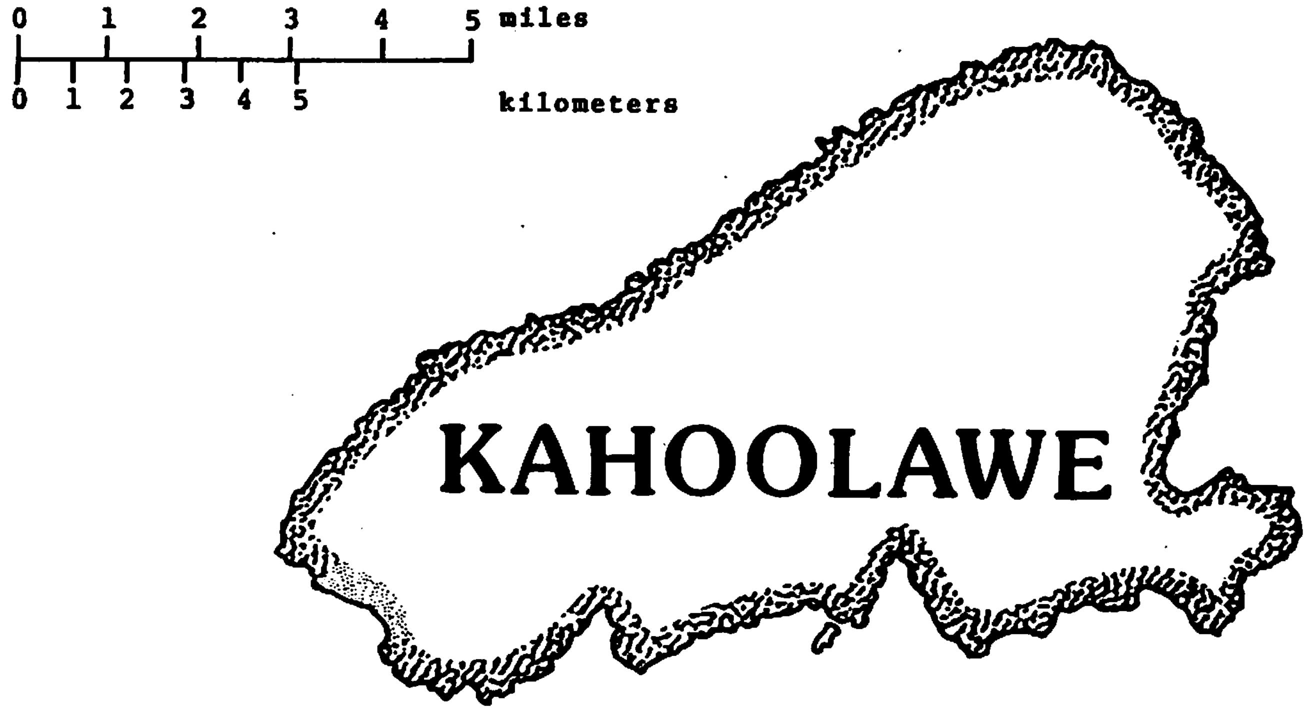
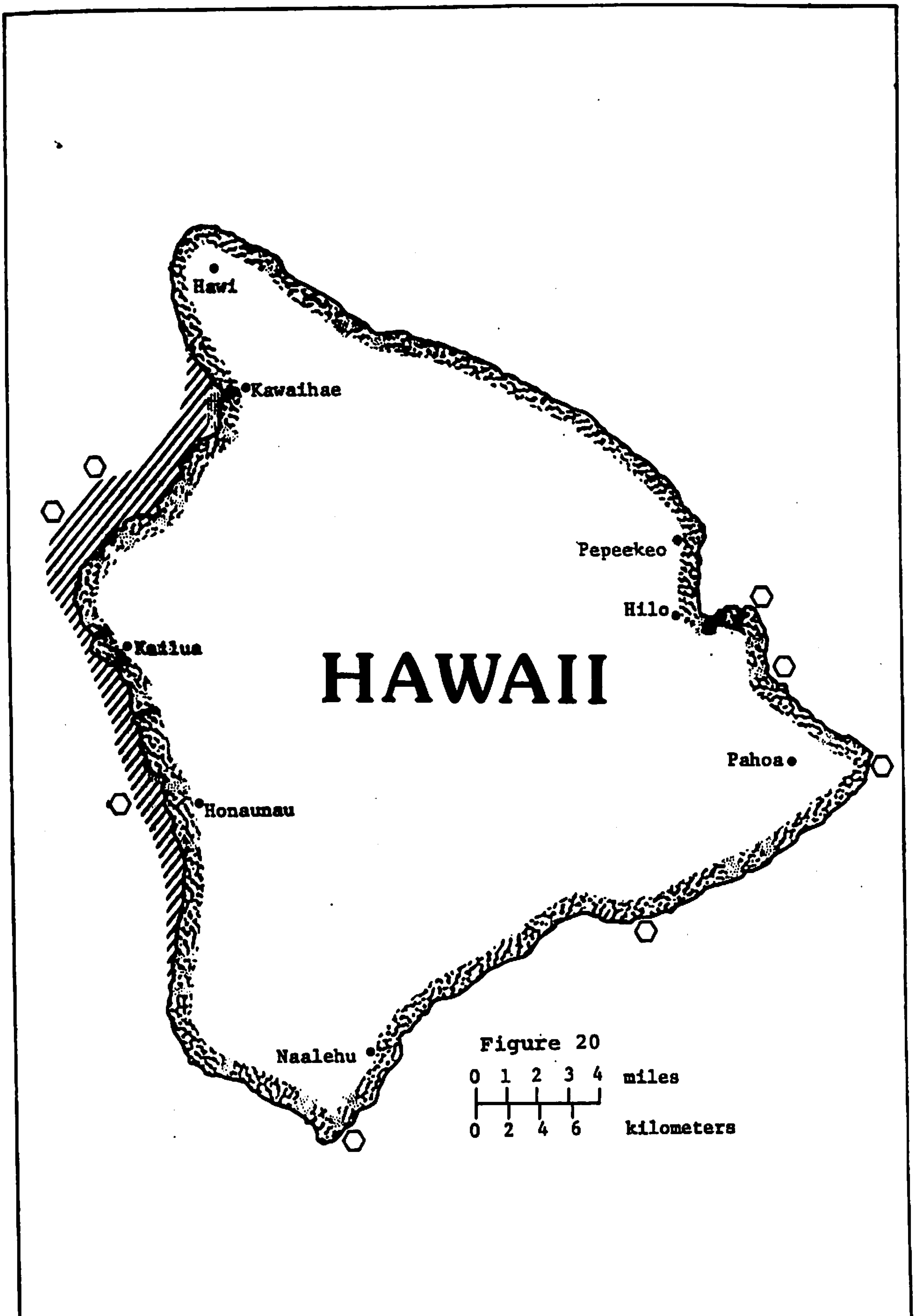

MAUI
Hana
Haiku
Kahului
Wailuku
Kihei
Keoneolo
0 1 2 3 4 5 miles
0 2 4 6 kilometers

Figure 18

Figure 19



S-09-373



Hawi
Kawaihae
Pepeekeo
Hilo
Kailua
HAWAII
Pahoa
Honaunau
Naalehu
0 1 2 3 4 miles
0 2 4 6 kilometers

Figure 20

Attachment 1

KEY TO HAWAIIAN MARINE BENTHIC ECOSYSTEMS

BASED ON ENVIRONMENTAL FEATURES

1.	Substrata often above sea level but intermittently flooded by high tides, wave splash and spray.	= Shoreline Ecosystems	--2
	Substrata usually below sea level (except possibly during low spring tides).	= Submerged Ecosystems	--5
	Substrata deeper than 40M below sea level	= <u>Deep Benthos</u>	
2(1)	Depressions in consolidated substrata where ocean water collects and forms semi-permanent pools.	= <u>Marine Pools</u>	
	Consolidated substrata raised above depressions or unconsolidated substrata too permeable for ocean water to collect and pond.	= Consolidated Rock Shorelines or Unconsolidated Sediment Shorelines	--3
3(2)	Substrata are consolidated rock of volcanic origin	= <u>Lava Rock Shorelines</u>	

(May be further subdivided into three types: cliffs, headlands and other vertical shores projecting high above sea level, with portions reached only by spray; basalt benches, solid horizontal platforms eroded by waves; boulder beaches formed of large rock fragments falling from above or eroded by storm waves.)

	Substrata are consolidated rock of marine origin unconsolidated volcanic or marine sediment or man-made.	= Solution Benches, Sand Beaches or Artificial Shorelines	
4(3)	Substrata are consolidated rock of marine origin	= Solution Benches	

(May be further subdivided into two types: Reef carbonate rock or raised reef; detrital carbonate rock composed of lithified sand.)

Substrata are unconsolidated volcanic or marine sediments = <u>Sand Beaches</u>

(May be further subdivided according to grain size of material, which depends on wave exposure; slope of beach, which depends on permeability of the sand and color, which depends on whether the material originated from basaltic lava (black), basaltic tuff (green), or calcium carbonate remains of marine plants and animals (white).

Substrata is man-made = <u>Artificial Shorelines</u>

5(1) Substrata protected or semi-protected from wave action --6

Substrata exposed to wave action --9

6(5) Substrata are principally eroded reef material, often mixed with land-derived sediments. --7

Substrata are principally reef-building organisms. --8

7(6) Substrata are shallow flat platforms of eroded reef material fringing the shoreline = <u>Nearshore Reef Flats</u>

Substrata are thick, extensive deposits of sediment, chiefly eroded reef material. = <u>Soft Bottom Communities</u>

Substrata are deep-water channels and basins of sand or silt maintained at a fixed depth by period dredging = <u>Artificial Basins</u>

8(6) Hard substrata (consolidated or broken reef or basalt), often sloping, which are dominated by reef-building corals. Scattered sand channels between rock. = <u>Wave Protected Coral Communities</u>

9(5) Shallow flat platforms of eroded reef materials separated from the shoreline by lagoons or open ocean and exposed to more wave action than fringing reefs. = <u>Offshore Reef Flats</u>

Hard substrata (consolidated or broken reef or basalt), often sloping, which are scoured by waves. Scattered sand channels between rock.

= Wave Exposed Reef Communities

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APPENDIX 2

JUSTIFICATION FOR MARINE WATER COLUMN STANDARDS

INTRODUCTION

The Proposed Marine Water Column Standards are the product of a unique approach to establish water quality criteria for the State of Hawaii. The basic philosophy in developing these proposed standards has been to consider water quality in reference to its impact upon marine ecosystem structure and dynamics. Historically, water quality criteria have, for the most part, been based upon land-use considerations.

Inasmuch as the proposed standards represent a significant departure from existing standards, justification of the proposed water quality standards is given in the pages that follow. This includes: (1) a rationale for the proposed parameters describing their importance to marine ecosystems, (2) a justification of the statistical form of the proposed standards, (3) documentation of the source material used as a data base for establishing the numerical ranges of the proposed standards and (4) a recommended sampling program to verify the proposed numerical values.

RATIONALE FOR PROPOSED WATER QUALITY PARAMETERS

The natural complexity of any marine ecosystem precludes complete definition or measurement. In applying an ecosystem approach to the establishment of water quality standards, appropriate parameters which represent key characteristics or attributes of the system must be selected to define the relative quality of the system. The selection of the proposed marine water quality parameters presented below has been based on the following criteria:

1. the parameters must have ecological significance,

2. the parameters should be sensitive to small changes,

3. the parameters should be easily measurable within the confines of available methodology and instrumentation,

4. preference should be given to parameters that can be measured in the field, thereby eliminating the logistical problems and errors associated with bottling and storing of samples,

5. sufficient background data should be available for Hawaiian waters for each parameter,

6. the parameters must have sufficient sensitivity such that they can indicate when water quality problems exist as well as when they are absent.

Obviously, few parameters can be expected to satisfy all these criteria. Nevertheless, the parameters chosen provide a working basis for the characterization of varied pelagic ecosystems and their responses to differing types and degrees of stress. The system of parameters chosen has a certain amount of internal correlation. Perturbations to a marine ecosystem rarely affect only one parameter. Usually, the response by an ecosystem to a given environmental perturbation is reflected throughout the ecosystem and can be observed in many of the parameters chosen for monitoring. The inherent integrity of the system is rarely disrupted except under the most severely stressed conditions. Each of the parameters chosen is discussed in detail below.

Salinity

Salinity is the concentration (by weight) of dissolved inorganic matter in one kilogram of sea water after all bromide and iodide have been replaced by the equivalent amount of chloride, and all carbonate converted to oxide. For practical reasons, salinity is usually measured indirectly as chlorinity, which is defined as the mass of halogens (chlorides and bromides) contained in one kilogram of sea water.

Because of the constancy of ionic ratios in sea water, chlorinity values can be converted to salinity using the following relationship:

$$S\ ^{o}/oo = 0.030 + 1.850\ Cl\ ^{o}/oo$$

when precipitation methods are employed (silver nitrate titration), or:

$$S\ ^{o}/oo = 1.80655\ Cl\ ^{o}/oo$$

when more precise conductimetric methods are used.

Salinity has two primary functions of ecological significance in the marine environment. First, the salinity regime is a major factor governing the distribution of marine versus estuarine communities. Second, salinity (in combination with temperature) determines the vertical density structure of the water column. Density structure (stratification) influences the productivity of phytoplankton by regulating vertical transport of nutrients. In open coastal waters, density stratification information is particularly important above offshore sewage outfalls to predict seasonal changes in dilution and distribution of the sewage field. Density stratification is also important in harbors and embayments in that it affects the circulation and flushing characteristics.

Temperature

Temperature is a measure of molecular kinetic energy. In the marine environment, temperature is commonly measured in units of degrees Celsius.

Temperature, like salinity, affects the distribution of organisms and the vertical density structure of the water column. The latter role is more important to the present discussion. Water column stratification, as discussed above, may limit vertical advective transport of nutrients. Since changes in nutrient distribution in the water column are responsible for seasonal variations in many of the parameters discussed below (e.g., light attenuation, suspended solids, and chlorophyll a), stratification assumes added importance. In low latitudes, stratification is primarily thermal in nature and thus temperature measurements are necessary to identify seasonal patterns.

Dissolved Oxygen

Dissolved oxygen is a measure of the quantity of free, atmospheric, oxygen dissolved in water. Dissolved oxygen can be reported in concentration units (i.e., mg/l, ml/l, or ppm) or as a percent saturation for a given salinity and temperature.

The marine environment is an aerobic, oxidizing environment and to remain as such, ample dissolved oxygen must be continually supplied. Dissolved oxygen is a necessary input for respiration in marine organisms and thus, oxygen concentrations sufficient to maintain these aerobic processes must be present. Under normal conditions in the Hawaiian marine environment, where the biochemical oxygen demand (BOD) is low, wind induced turbulence at the water-air interface ensures sufficient gaseous exchange such that the surface waters are usually oxygen saturated. In addition to this purely physical exchange of oxygen, marine plant productivity (benthic and pelagic) can also exert a significant diurnal influence on oxygen levels. This can be seen from the basic photosynthetic equation:

$$6\ CO_2 + 6\ H_2O \xrightarrow[\text{light}]{} C_6H_{12}O_6 + 6\ O_2$$

During daylight hours, oxygen levels in the water column tend to increase where large populations of primary producers exist. At night, however, the situation reverses and oxygen levels tend to decrease due to respiratory processes. This diurnal fluctuation is most pronounced in highly eutrophic environments such as Pearl Harbor where complete oxygen depletion may occur in the water column before dawn. It is suspected that several "fish kills" in Pearl Harbor have been caused by oxygen depletion.

Isolated areas in open coastal waters could experience oxygen stress due to direct influences of man such as thermal effluent discharges or oil spills. Most changes in dissolved oxygen concentrations, however, are likely to be indirect results of other perturbations such as inputs of nutrients, biochemical oxygen demand (BOD) from organic-laden effluents, oil spills, and storm runoff. Stratified embayments with anaerobic sediments have bottom water layers with reduced oxygen tensions. Prolonged low oxygen conditions are likely to correlate with high levels of suspended sediment and nutrient loading, high coefficients of light extinction, and high turbidity values.

Light Extinction Coefficients

Light extinction coefficients are a measure of the rate at which light is attenuated in the water column and are calculated as per the following formula:

$$k = -\ln (100/L)/Z$$

where 100 represents the percent incident light at the water surface, and L is the percent of surface light remaining at depth Z.

The extinction of light during its passage through the water column is due partly to particulate matter (living and non-living) in the water and partly to molecular action of the water and its dissolved contents. The light extinction coefficient may be used to estimate the depth of the compensation point, which is the depth at which light energy has been reduced to one percent of the surface intensity. This roughly approximates the depth to which net primary production may occur, i.e., that depth at which oxygen evolution by photosynthesis equals oxygen consumption due to respiration. In open ocean waters around Hawaii, light attenuation is low due to the typically low particulate content of these waters. The compensation point is generally greater than 100 meters in depth. In eutrophic environments where large amounts of living particulate matter occur (e.g., Pearl Harbor, Ala Wai Canal, South Kaneohe Bay), the compensation depth may occur within the upper few meters of the water column. Under such conditions, oxygen availability to the underlying water column and benthic community may become severely restricted. Extinction coefficients are also a sensitive measure of suspended solids loading.

Variations in light extinction values are a vertically integrated response to both living and non-living particulate matter in the water column. This phenomenon is an asset that makes light extinction values a particularly useful parameter in any water quality monitoring program. Light extinction values are sensitive to changes in suspended solids, turbidity, nutrients (indirectly) and chlorophyll a. Radical changes in dissolved oxygen levels, furthermore, rarely, if ever, occur without concommitant changes in nutrient or chlorophyll concentration. Hence, only temperature and salinity variations in the marine environment have no direct significant effect on light extinction values. The broad interrelationships of many of the other water quality parameters with light extinction make the latter a singularly important measurement for all water types.

Non-Filtrable Residue

Non-filtrable residue is a dry-weight measure of the particulate material filtered from a known volume of sea water. This usually includes both organic and inorganic material which can be distinguished, if desired, by separate determinations of both total and volatile non-filtrable residue.

Non-filtrable residue is composed of phytoplankton, detritus, sediment and microzooplankton. High non-filtrable residue concentrations are usually caused by either dense phytoplankton concentrations and/or by suspended material of terrigenous origin. The terrigenous sediment fraction is ecologically significant in that it can be quite detrimental to both pelagic and benthic communities. Primary productivity is reduced by suspended materials that restrict sunlight penetration through the water column. Excessive suspended material can also cause deleterious abrasion of gill tissue in fish and clog the filter feeding organs of certain zooplankton. For the purposes of water quality management, suspended sediment is important as it influences dissolved oxygen levels, light extinction and nutrient sorption-desorption kinetics in the water column. Clearly, non-filtrable residue measurements have aesthetic importance and depending on the origin of the solids, can have public health significance. Water heavily laden with suspended material is visually unappealing and incompatible with the aesthetic ideal of unpolluted, oligotrophic Hawaiian waters. When the solids originate from municipal sewage outfalls, a clear potential public health problem exists relative to water contact sports.

Turbidity

Turbidity is a measure of the light scattering properties of suspended material in a water sample. Being an optical measurement, turbidity is affected by the size, shape and refractive index of the suspended particles. These properties can be quite variable, and quantitative comparison of different sets of turbidity data may be misleading in the absence of concurrent dry weight data. Turbidity is measured against Formazine standards (or the equivalent) in a nephelometric instrument. A nephelometer measures light scattering at 90 degrees from the angle of incidence. In contrast to non-filtrable residue measurements which require considerable laboratory time and equipment, turbidity can be easily measured in the field with portable instrumentation. This is a significant advantage in that it provides immediate feedback capabilities useful in tracing the sources of turbidity plumes.

In undisturbed oligotrophic Hawaiian waters, the natural phytoplankton populations create little turbidity. Intermittent inputs of terrestrial sediments, however, can impart highly turbid qualities to coastal waters. The ecological significance is similar to, though less definitive than, non-filtrable residue measurements. However, turbidity measurements provide a convenient assay of water clarity, an important aesthetic consideration in the establishment of water quality standards. Unlike light extinction measurements which vertically integrate the effects of particulate matter through the water column, turbidity measurements provide an estimate of particulate matter concentrations at discrete depths. Turbidity measurements may replace light extinction measurements in very shallow areas and provide an important means of identifying the source(s) of particulate matter input to the marine environment. Turbidity measurements are useful to monitor high runoff conditions, point discharges or human activities that affect water clarity in some open coastal areas, harbors and embayments. Some human activities and their by-products which affect turbidity values and have the potential for creating undesirable conditions in water column communities are: (1) municipal sewage effluents, (2) storm drain effluents, (3) industrial discharges, (4) agricultural runoff, (5) poor grading practices, (6) dewatering of construction sites, (7) harbor dredging, (8) bilge pumping and (9) ocean thermal energy conversion (OTEC) effluents (indirectly).

Nutrients

Primary productivity in tropical open ocean waters is generally regulated or limited by nutrient availability. The nutrients most often limiting productivity are nitrogen and phosphorus. The relative scarcity of these nutrients is responsible for the pristine nature of the oceanic waters surrounding Hawaii. Shoreward, however, the availability of these "limiting" nutrients tends to increase due to terrigenous influences. The increase in water column biomass from oceanic waters through transition and open coastal waters to embayments is directly attributable to these increases in nutrient availability. Thus, nutrients are considered to be basic and essential factors in assessing water quality from an ecosystem standpoint.

Nutrient concentrations can be substantially affected by a variety of natural and man-made factors. A list of these operatives should include, but is not necessarily limited to: (1) seasonal changes in advective transport, (2) seasonal changes in phytoplankton and zooplankton population dynamics, (3) municipal sewage effluents, (4) storm drain effluents, (5) industrial discharges, (6) agricultural runoff, (7) construction site dewatering effluents, (8) harbor dredging, (9) bilge pumping and (10) ocean thermal energy conversion (OTEC) effluents.

Inasmuch as nutrients in their various forms play such a fundamental role in establishing and maintaining water quality, it is important to monitor several forms.

1. Immediately Available Nutrient Fractions

The soluble inorganic nutrients comprise the bulk of those that are immediately available for phytoplankton uptake. These nutrients include ammonia, nitrite, nitrate, and orthophosphate. Spectrophotometric techniques for these analyses are routine for most water quality laboratories. Since nitrite concentrations are extremely low in Hawaiian waters, it is recommended that a measurement of the sum of nitrite and nitrate be adopted as a parameter, and be reported as one concentration without further partitioning.

The inorganic nutrients are relevant to water quality management in that they are generally the limiting substrate regulating the growth of phytoplankton. Shock loadings of these nutrients as a result of human activities or natural causes can create sudden phytoplankton blooms that may adversely affect other segments of the ecosystem, as for example when the bloom species secretes toxic substances. Sometimes, the dominant nitrogen forms found in the water column are a valuable clue to the source of the nutrients. Concentrations of inorganic nutrients vary seasonally in response to changes in terrigenous inputs and to vertical advective transport of nutrients when stratification breaks down.

2. Complexed Nutrient Fraction

The complexed nutrients are bound in organic molecules in either particulate or soluble forms. The particulate forms are comprised largely of living biomass and detritus while the soluble forms are extracellular excretion products and by-products of bacterial decomposition. The soluble organics include some amino acids, urea, and a variety of both growth stimulating and inhibiting substances that are not well defined. Organic nutrient analyses can be performed either for total or soluble portions using unfiltered or filtered samples respectively. These analyses cannot be carried out in the field and require pretreatment by acid digestion. Large numbers of organic nutrient determinations can, realistically, only be carried out using automated equipment.

Organic nutrient measurements must be performed in order to assess the total fluxes of nitrogen or phosphorus in the marine environment. Mass budget calculations which assess the relative importance of various nutrient sources and sinks require that all forms be analyzed. Organic nutrient analyses are especially relevant in assessing the performance of deep ocean sewage outfalls. Organic nutrient values vary seasonally due to changes in vertical advective processes in the water column and also changes in terrigenous inputs.

A clear concensus on which nutrient parameters should be included in a water quality monitoring program is difficult to attain. One approach is to report only total nitrogen and phosphorus values (this in fact requires three separate analyses and not two as is implied). Another approach is to report total and inorganic forms (kjeldahl nitrogen, total phosphorus, orthophosphate, ammonia, nitrite, and nitrate). If, however, in addition to these measurements, determinations for soluble organic nitrogen and phosphorus fractions are performed, then, all major nutrient fractions are tallied. Several reasons supporting the breakdown of nutrient data into these various fractions follow.

1. Knowledge of the ratio of inorganic N to P has a significant bearing on which nutrient will be limiting and which plants are likely to be stimulated by the available nutrients. Phytoplankton require atomic ratios of inorganic N to P of between approximately 8 and 16. Ratios of around 20 and above will be phosphorus limiting. Ratios below 8 are likely to be nitrogen limiting.

2. Knowledge of the relative quantity of organic and inorganic nutrients available in the water column is a primary measure of the degree of eutrophication. In open ocean and transition waters, nutrients are almost entirely in the organic form and inorganic nutrients are scarce. Inorganic nitrogen, for example, is typically almost entirely in the form of ammonia and is present only in low concentrations. The proportion of inorganic nutrient forms increases either with depth or with proximity to shore (eutrophication). In highly eutrophic environments where light limits the growth rate of phytoplankton, high concentrations of inorganic nutrients are found in excess of the assimilative

capacity of the phytoplankton population.

3. Some value exists in clearly delineating all nitrogen forms as opposed to "total-N" because there is no standard definition for total-N. Some authors equate total-N with kjeldahl-N (i.e., total organic-N plus ammonia) as opposed to summation of all possible nitrogen forms. A true total-N value requires an analysis of kjeldahl-N (on an unfiltered sample) plus a combined measurement for nitrite and nitrate (using a cadmium reduction column). Unfortunately, these distinctions have not always been delineated in environmental studies and therefore the concentrations of nitrogen reported are less useful.

4. Nitrate-nitrogen (measured as nitrite plus nitrate) is, as a single inorganic nutrient, a convenient measure of the degree of eutrophication. In open ocean environments, inorganic nitrogen (generally the limiting nutrient) is rapidly recycled. The net result is that ammonia values are extremely low and nitrate is virtually non-detectable. In eutrophic environments where nitrogen is limiting, the inputs of inorganic nitrogen as ammonia to the water column exceed the uptake capacity of the phytoplankton population and some of the excess ammonia is oxidized to nitrate by bacteria. Hence, except in cases where ground water inputs are significant, nitrate values alone are a good measure of the degree of eutrophication of a water column community.

A comprehensive water quality program should include at a minimum the following nutrient analyses: kjeldahl nitrogen, ammonia, nitrite plus nitrate, total phosphate, and orthophosphate. From these data the concentrations of organic nitrogen, organic phosphorus, and total nitrogen (summation of kjeldahl nitrogen and nitrite plus nitrate nitrogen) can be ascertained.

Chlorophyll a

Chlorophyll *a* is the primary photosynthetic pigment in all living plants. It is commonly measured with either a spectrophotometer or a fluorometer following an acetone extraction. The fluorometric measurement has several relative advantages including a higher sensitivity, a smaller sample volume requirement, and the rapidity of the measurement.

Chlorophyll *a* measurements are used as an estimate of phytoplankton biomass in marine waters. Phytoplankton perform a very basic function in the pelagic environment as the primary energy source for the entire food web. As the primary producers, any environmental factors that affect phytoplankton productivity or biomass will be reflected throughout the entire food web. Further, most of the water quality parameters considered herein affect phytoplankton productivity and/or biomass either directly (e.g., light extinction, nutrients, oxygen) or indirectly (e.g., turbidity, suspended solids, temperature, and salinity). Therefore, phytoplankton represent a focal point for relating human activities and any resultant changes in water quality to the entire pelagic community.

The primary significance of chlorophyll a measurements to water quality management is that they serve as a sensitive, rapidly responding indicator of environmental perturbations in marine ecosystems. They are valuable as tracers of the source of chemicals with stimulatory or inhibitory effects and also provide a first indication of impacts on the pelagic ecosystem. In conjunction with selected chemical and physical parameters, chlorophyll a determinations can help define the extent and impacts of both point and non-point sources. On a long-term basis, the steady-state phytoplankton biomass reflects the relative state of eutrophication existing in a given area.

JUSTIFICATION OF STATISTICAL FORM OF THE PROPOSED STATE OF HAWAII WATER QUALITY STANDARDS

The proposed standards for nutrients, chlorophyll a, and various measures related to suspended material and light penetration are written in a statistical form that specifies the geometric mean, the upper decile, and a not-to-exceed level.

The geometric mean was chosen to represent the central tendency of these parameters because it has been noted that distributions of these parameters in Hawaiian waters (and elsewhere) are well approximated by log-normal distributions. This is not surprising since the log-normal distribution is particularly applicable to phenomena that are bounded on one side and are a result of a multiplicative mechanism acting on a number of causative factors. Such a set of conditions is more applicable to the parameters in question than is the set of conditions associated with a normal distribution (i.e., unbounded on both sides, symmetrical, and resulting from an additive mechanism of causative factors).

Other pertinent characteristics of the log-normal distribution are that the logarithms of the numerical values are normally distributed and that the geometric mean coincides with the median. Because the parameters in question were observed to be log-normally distributed with time under natural conditions, it is inappropriate to imply a normal distribution by specifying the arithmetic mean as a central value. It is even more inappropriate to specify single number standards (as in the present State Water Quality Standards) since this does not take into account the reality of the actual variation of these parameters.

The proposed standards are written so as to accommodate the greater or lesser temporal variations of these parameters in the various proposed water classifications (i.e., wet, dry, and seasonally wet embayments; wet, dry, and seasonally wet open coastal waters; transition waters; oceanic waters; and streams). These variations were included in the proposed standards by the specification of the upper decile level along with the geometric mean. This means that the proposed standard is defined as a cumulative statistical distribution as specified by a straight line through the geometric mean (i.e., 50 percent value) and the upper decile level (i.e., 90 percent less than the specified value) as plotted on log-normal probability paper.

The third value of the standard, the not-to-exceed level, is the 98 percent less-than value that was obtained by extending the line passing through the geometric mean and the upper decile point. The main purpose of the not-to-exceed value is to serve as an enforcement tool for short-term discharges (i.e., less than 10 percent of the time).

An example of the form of the proposed standards is given in Figure 1 using the total phosphorus standards for saline waters. The values for the geometric mean and the upper decile are taken from statistical analyses of existing data gathered by several agencies and investigators from areas judged to be representative of the several classifications of waters with no marked man-made influences. For comparison purposes, the present single value standards for total phosphorus in classes AA, A, and B are also shown on the figure.

These proposed standards clearly accommodate the real conditions of higher concentrations and more variations closer to the shoreline, in embayments, and in areas with significant freshwater discharges.

The basic philosophy used in obtaining the numerical values for the proposed standards is one of nondegradation relative to generally desirable representative areas of the several water classifications.

In most cases the numerical values of the proposed standards are from statistical analyses of existing data. In some cases, where the existing data were not extensive, minor adjustments were made to the results of the statistical analyses in order to produce proposed standards that are self consistent. In a few cases, where there is little existing data (primarily non-filtrable residue), the numerical values for the proposed standards are estimates based on the existing data, the expected variation, and the best judgment of the committee members.

A three-year sampling program is recommended to fill in the gaps in the existing data and to obtain a firm and consistent data base for the entire set of proposed standards. A description of the recommended sampling program is given in another portion of this justification paper.

In general, the sampling requirements to test compliance with the various standards are dependent on the natural variability of the parameters in question, the acceptable variation from the true value, and the desired level of confidence that the measured value is within that acceptable variation. For the parameters with the largest variations, a reasonable requirement is that a sufficient number of random samples be taken over a period of one year to be 95 percent confident that the measured geometric mean is within about 20 percent of the true geometric mean (this is approximately the same as being 70 percent confident that the measured geometric mean is within about 10 percent of the true geometric mean).

An example of the calculated confidence intervals related to the proposed total phosphorus standard is given on Figure 2. The calculation is based on 36 samples (12 times a year at three depths) and on the assumption that the measured concentrations are log-normally distributed around the "true" values given by the standard. The general formula for these confidence intervals is the following:

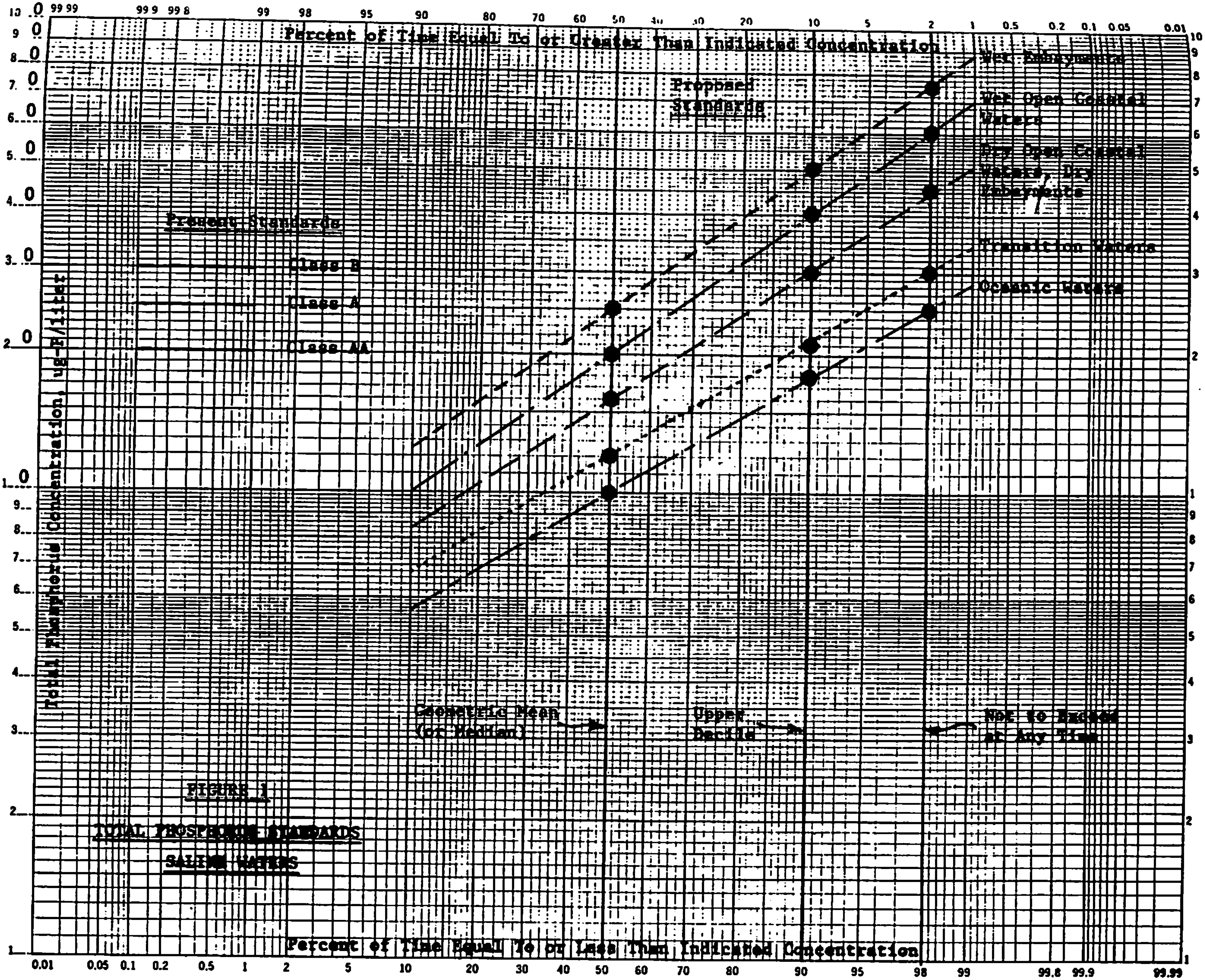

FIGURE 1

TOTAL PHOSPHORUS STANDARDS

SALINE WATERS

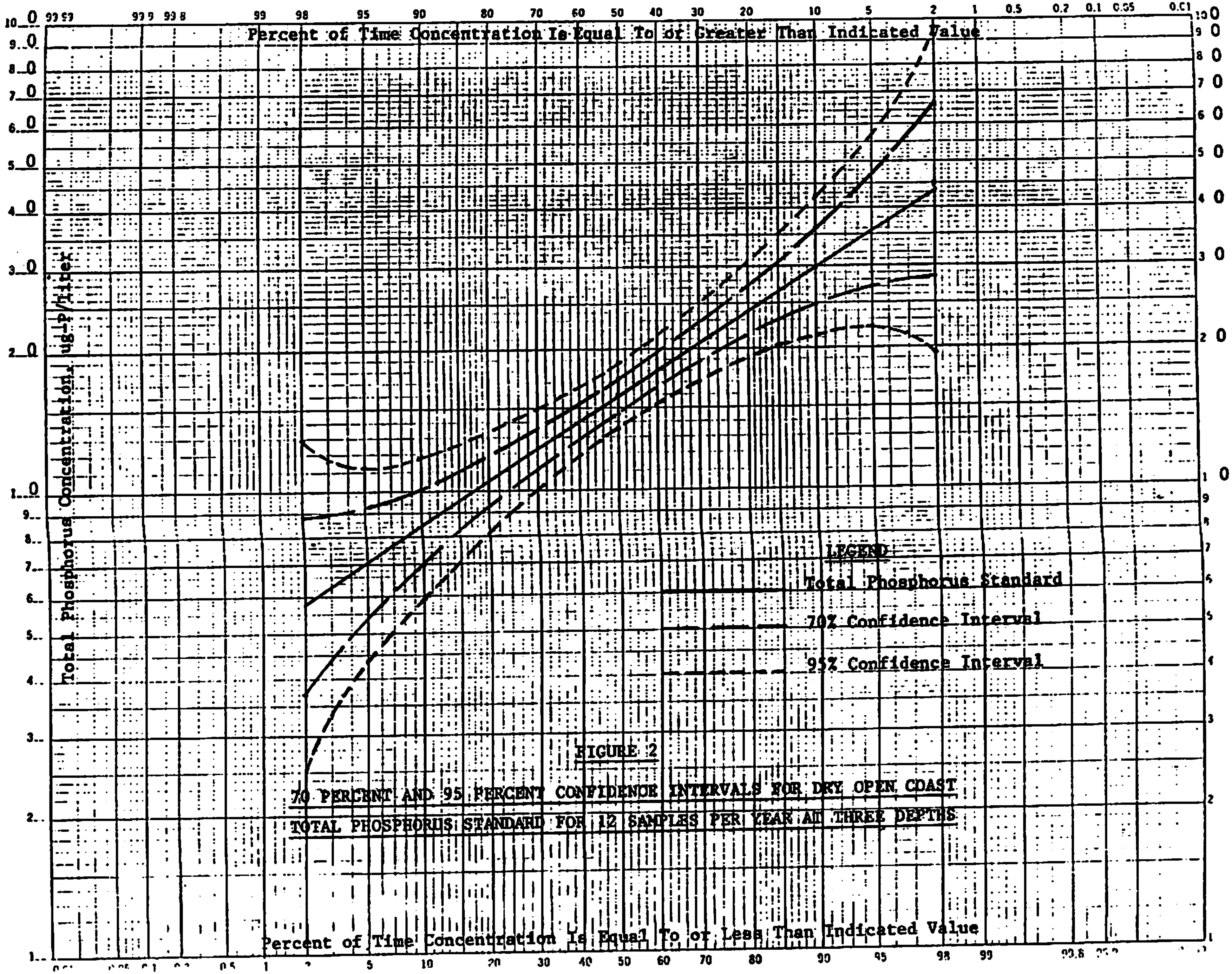

FIGURE 2

70 PERCENT AND 95 PERCENT CONFIDENCE INTERVALS FOR DRY OPEN COAST TOTAL PHOSPHORUS STANDARD FOR 12 SAMPLES PER YEAR AT THREE DEPTHS

$$\text{Confidence interval at } F_{(c)} = \exp\left[\ln C_{F(c)} \pm \frac{(u)\ (\sigma_m)}{\sqrt{n\left(1 - \frac{|F_{(c)}-50|}{50}\right)}}\right]$$

Where: $F_{(c)}$ = cumulative distribution function percent frequency

$C_{F(c)}$ = "true" concentration at $F(c)$

σ_m = standard deviation of the normal distribution of lnC

n = number of samples

u = normal distribution factor related to desired confidence interval (1.96 for 95 percent and 1.04 for 70 percent)

The results of these calculations, as shown on Figure 2, indicate that the 95 percent confidence interval at the geometric mean (or median) is about $\pm$17 percent with 36 samples. With about 28 samples, the interval is about $\pm$20 percent. Since almost all of the standard deviations of the standard parameters are generally close to that of the total phosphorus used in the example, it is recommended that a compliance testing program consist of at least 30 samples (i.e., ten times at three depths).

SUMMARY

1. The proposed saline water standards for nutrients, chlorophyll <u>a</u>, and suspended solids and light absorption characteristics are expressed as log-normal distributions because this corresponds to the observed data distributions in Hawaiian waters.

2. The numerical values for the proposed standards are based, for the most part, on existing data from areas judged to be in a generally desirable condition. For some parameters in some water classifications where insufficient data presently exist, the proposed numerical values are based on the best judgment of the committee members, taking into account existing data, overall consistency, and statistical requirements.

3. A three-year sampling program is recommended to obtain a consistent data base for the entire set of proposed standards.

4. For the proposed standards in the statistical form, compliance testing would consist of a minimum of 30 samples (i.e., ten times

at three depths), based on the general guideline of being 95 percent confident that the measured geometric mean is within 20 percent of the "true" geometric mean.

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RECOMMENDED SAMPLING PROGRAM FOR MARINE WATER COLUMN

Oceanic and Transition Waters

I. Stations - two control stations for each water type; one to be located off Kauai and one off Hawaii where transition and oceanic waters lie within the State's three mile limit

II. Frequency of Sampling
Alternatives: A. monthly sampling for first year followed by quarterly sampling next two years (optimal)
B. quarterly sampling for three year interim period

III. Sampling Depths - replicate samples at all depths:
1 meter
10 meters
30 meters

Coastal Waters

I. Stations - one control station for each category (i.e., dry, seasonally wet and wet) on the following islands: Kauai, Oahu, Maui, Hawaii

II. Frequency of Sampling
Alternatives: A. monthly for three years (optimum)
B. monthly for first year followed by quarterly sampling next two years

III. Sampling Depths - replicate samples at all depths:
A. Water depth less than 30 meters:
1 meter
1 meter off bottom
halfway between upper and lower sampling depths
B. Water depth greater than 30 meters:
1 meter
10 meters
30 meters

Embayments

I. Stations
A. Hanalei Bay, Hanamaulu Bay, Nawiliwili Bay, Hanapepe Bay, Kaneohe Bay (3 stations - southern, middle, northern bay), Pearl Harbor, Hanauma Bay, Hilo Bay
B. Kahului Harbor, Keehi Lagoon, Ala Wai Boat Harbor, Kailua Harbor

II. Frequency of Sampling
A. stations - monthly sampling for three years

B. stations - quarterly sampling for three years

III. Sampling Depths - replicate sampling at all depths:

½ meter

1 meter off bottom

halfway between upper and lower sampling depths

APPENDIX 3

JUSTIFICATION FOR MARINE BOTTOM STANDARDS

INTRODUCTION

The biological effects of a pollutant fall into two time dimensions: (1) effects in immediate response to a dose of a pollutant; (2) secondary and tertiary effects which take place later and often some distance from where a pollutant was introduced.

To cover both time dimensions, water quality standards should be a blend of (1) sensitive parameters that respond quickly to small changes in water quality; and (2) relatively insensitive parameters that are more stable and respond only to long-term changes in water quality (Environmental Consultants, Inc., 1976).

The frequently performed, routine monitoring program should be built around the first category of parameters and should emphasize pelagic (water column) indicators because they are sensitive and responsive to short-term perturbations. The response time of benthic (bottom) ecosystems is generally too slow to chronicle short-term changes in water quality, so benthic indicators are of little or no value for routine monitoring and day-to-day policing of standards.

However, the continuous removal and replacement of water and its contents in aquatic ecosystems does not permit an assessment of long-term changes in the environment through phytoplankton, which are short-lived and have high reproductive rates.

Changes on or in the bottom are less transitory than those in overlying waters, so benthic indicators are preferable for long-term stresses. The more sedentary organisms which live within, on the surface of, or closely associated with the substrata at the base of the water column must "sit and take it." The time scale of ecological change on the bottom is much longer than changes in the water column. Benthic ecosystems are less sensitive to short-term stresses but for the same reasons, recovery from long-term or repeated stress is very slow. There are three purposes for bottom related standards:

1. It is probably less common for a single factor to impose a clear-cut limit on an ecosystem than for more complex interactions to occur. There is little reason to suppose that particular pollutants can be singled out or isolated as the cause of long-term changes in water quality. Water quality standards may not be exceeded individually but the long-term integrated effects of all environmental factors acting in combination may indicate degradation. Two or more factors acting in combination may produce results which could not have been predicted on the basis of knowledge of the action of single factors taken one at a time. In some cases, factors may

tend to cancel one another (antagonism) but in other cases, the combined effect may be more severe than the simple sum of the two acting separately (synergism). Synergistic effects may be revealed through the integrated responses of benthic ecosystems.

2. The effects of low-level chronic pollution are likely to be expressed as gradual changes over fairly long periods of time. Benthic ecosystems provide "ledgers" of fluctuating environmental conditions. Discontinuous and sporadic events or chronic low levels of exposure may be "recorded."

3. Long-term changes in benthic ecosystems provide feedback for evaluating whether or not the goals of the State's water quality program are being attained and for revising standards if they are not achieving desired results.

The need to establish water quality standards obliges decisions to be made in the absence of adequate information. In a sense, water quality standards are always interim, for they can always be improved by more information. It is important to recognize that the bottom-related standards proposed on the following pages do not have as sound a factual basis and are more speculative than the water column standards. The reasons for this are (1) there are fewer standardized benthic indicators than pelagic indicators and (2) the accumulated body of knowledge about long-term changes on the bottom is meager compared to the accumulated data about short-term changes in the water column. However, our inability to establish very precise standards for the bottom does not detract from their importance and does not eliminate the need for such standards. The time to include consideration of trends in the chemical, physical and biological characteristics of the bottom in water quality standards is now.

OXIDATION-REDUCTION POTENTIAL

Rationale For Standard:

Of the several factors that have been shown to influence the exchange of materials between sediments and the overlying water column, the most important is the degree of oxidation or reduction ("redox potential") of sediment interstitial waters. Redox potential reflects the availability of free oxygen in sediments.

Redox potential is a measure of electron availability within the sediment pore water system. Electrons are essential to all inorganic and organic chemical reactions. A chemical species which loses electrons is said to become oxidized. Alternately, reduction is a gain of electrons. Thus a measure of the redox potential of a sediment-water system reflects the degree of oxidation or reduction of the various chemical species in the system.

If the rate at which processes requiring oxygen (such as respiration and decomposition) exceed the rate at which oxygen is produced or supplied, then the bottom environment approaches a reduced condition and free oxygen disappears. If oxygen is well supplied relative to its rate of consumption, then the environment is oxidized. Most higher forms of life and aquatic communities in Hawaii and elsewhere live in oxidized environments, although some communities can better tolerate reduced environments than others and a few important communities can live in reduced environments.

In an aqueous system, the degree of oxidation is limited by the electro-chemical potential at which water becomes unstable and is oxidized to molecular oxygen. The limit of reducing conditions in an aqueous system is the potential at which the hydrogen in water is reduced to molecular hydrogen. Within these limits imposed by the stability of water, the oxidation states of hydrogen, carbon, nitrogen, oxygen, sulfur and many metals may be affected by redox potential, although the measured redox potential is largely determined by a few of the more abundant of these elements in the system (Khalid, et al., 1975).

Of the major elements represented in sediment pore waters, some of the greatest concentration changes that occur during shallow burial are exhibited by carbon, nitrogen and sulfur, each of which is directly or indirectly due to the decomposition of organic matter by micro- and metazoan organisms (Price, 1973).

Most chemical reactions in the natural environment involve both electrons and protons. pH is a measure of the availability of protons for reaction with a base. To predict a chemical environment in which a particular chemical species may be found, one would have to describe the range of both the redox potential and the pH at which that species is stable. pH and redox potential are not entirely independent properties of aqueous systems. All important reduction reactions that occur in natural systems involve the consumption of hydrogen ions. Thus, a change in either of these properties involves a change in the other. However, there is a tendency for sediment material to become buffered around neutrality, particularly in the marine environment. This usually limits the range of chemical reactions and places more importance on the role of redox potential in regulating the chemical forms and transformations of trace metals and plant nutrients.

Sediments generally contain a considerable amount of residual organic material. This organic matter is derived primarily from the death and decay of plant and animal tissue from pelagic and benthic organisms. Additional organic carbon is added from soluble and particulate organic material associated with surface and subsurface land drainage and waste discharges into receiving waters. As a result, there is usually an ample supply of substrate for the large populations of bacteria within the sediments and microbiological activity is high.

Most of the chemical reactions in sediment-water systems are biologically mediated. As organic matter is used by bacteria as a food source, some reducible substance in the sediment environment must be available to accept the electrons resulting from microbial respiration.

In an idealized model, the sequence of reducible substances is predictable, starting with oxygen, and progressing to nitrite-nitrate and the oxidized forms of iron and manganese when the demand for oxygen exceeds the supply. Finally, redox potential is sufficiently low for fermentation and reduction of sulfate and carbon to take place. The chemical reaction sequence is paralleled by a succession of microorganisms from aerobic heterotrophs to anaerobic and facultative anaerobic organisms (denitrifiers, fermenters, sulfate reducers, methane bacteria).

Natural sediment-water systems typically consist of a diverse mixture of inorganic and organic compounds, so that redox potential does not exhibit the precise, step-like model and the mixture of redox potentials tends to change gradually.

In theory, redox potential measurements are made with electrodes inert to the chemical species in the sample. In practice, no electrode material is completely inert. However, gold or platinum electrodes have been used successfully in making redox potential measurements. Redox potential measurements can quantitatively describe the ionic distribution only between chemical species which may interact with the transfer of electrons. In a natural system, there are usually many redox couples present and not all redox couples are chemically interactive with others. Unless the concentration of a given redox couple is relatively high, inert electrodes (generally platinum) used for redox measurements are not specific for a single redox couple. Thus the electrode responds to the electrochemical potential of all redox couples present. If an equilibrium were assumed in a system containing many redox couples, the tendency for some chemical species to donate electrons is balanced by the tendency for others to accept electrons. The measured redox potential would be a mixed potential which reflects a weighted average of the potentials contributed by each of the redox couples present in the system. Due to the almost continuous addition of organic matter which may be oxidized and thus serve as an electron donor, a redox equilibrium is almost never attained in a natural system. Several redox couples, each having greatly different potentials as separate redox systems, may be added together to produce a mixed potential which differs several hundred millivolts (mv) from the potential of the individual couples.

The previous discussion briefly described some of the problems associated with redox potential measurements. However, the problems should not mask the utility of these measurements. In spite of the theoretical limitations involved in the use of redox potentials to quantitatively describe a specific ionic distribution in a mixed system, these measurements have been successfully applied in soil and sediment chemistry to characterize the oxidation-reduction transformations of many metals and plant nutrients (Khalid, et al., 1975).

In order to have some concept of the degree of oxidation or reduction indicated by redox potential measurements one must be able to associate numerical redox values with the chemical transformations that are occurring. There are far too few data reported for Hawaiian waters to establish a standard for redox potential solely on the basis of local experience. However, the few measurements that are available illustrate the importance of establishing a standard for redox potential.

As illustrated in Figure 1, the oxidizing sediment environment ($E_H > +200$ mv) of the reef flats of Kaneohe Bay's barrier reef (F) contrasts sharply with the strongly reducing sediment environment ($E_H < -100$ mv) of the reef flats near Coconut Island (C) (Sorokin, 1973).

It can be seen from the redox potential profiles drawn by Sorokin (Figure 1) that the chemical environment may vary considerably within a sediment profile, becoming more reducing with depth. Sorokin and others' measurements suggest that aquatic ecosystems characterized by good water motion can be expected to have oxidized sediment bottoms while ecosystems with poor water motion (compounded by ample organic material settling from the water column) can be expected to have reduced sediment bottoms. For this reason, the interim standard proposed on the following page recognizes two levels of stringency.

The higher level of stringency applies to benthic ecosystems that do not have reducing sediment bottoms as a result of natural causes. In these ecosystems, the chemical environment of sediment bottoms should remain oxidizing for the protection of resident infauna. Damage to the decomposers in the ecosystem is a potential source of instability

Figure 1

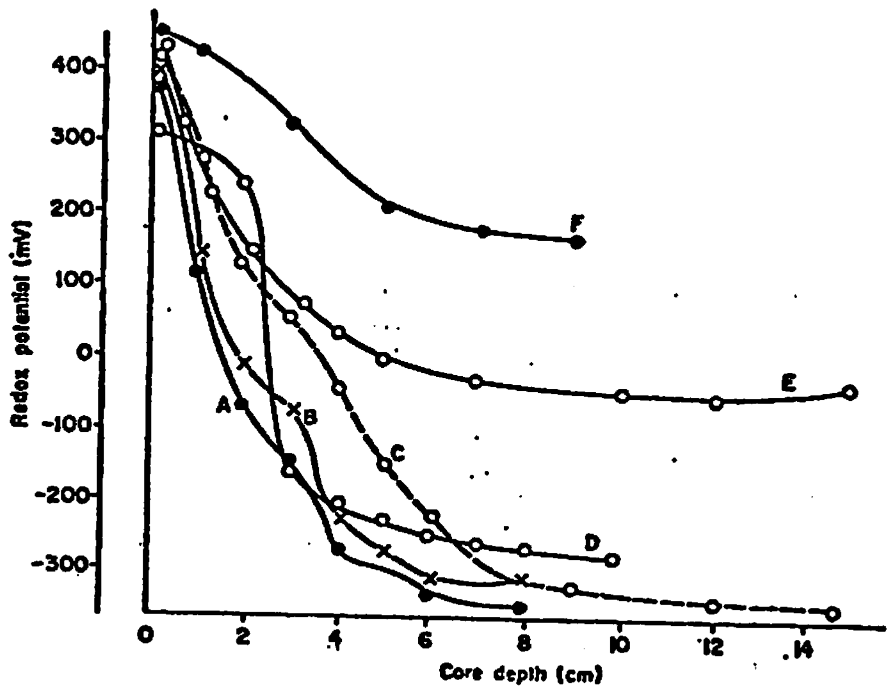

Figure 1. The redox potential of reef sediments. A, fine sediments among dead corals on the western edge of the reef at Coconut Island, Kaneohe Bay, close to the polluted area; B, coral sand on the internal reef opposite Coconut Island; C, coral sand on the southeastern edge of polluted Coconut Reef (Kaneohe Bay); D, fine, powdery mucoid sediment from the clean part of the internal reef of Majuro Atoll; E, coral sand from Majuro Atoll; F, coral sand from the external Kapapa Reef, Kaneohe Bay.

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greater perhaps than that arising from tampering with the more visible predator-prey relationships of the system. Literature reviews suggest that maintenance of an oxidizing sediment environment requires that redox potential (E_H) not be less than +100 mv.

The lower level of stringency applies to benthic ecosystems that often have reducing sediment bottoms as a result of natural causes. Redox potential in reducing sediments generally ranges from +100 mv to -400 mv (Gambrell, et al., 1976). In these ecosystems, resident infauna are probably better adapted to somewhat reduced conditions. Many species may compensate by ventilating their burrows or turning over and aerating sediment. However, strongly reduced environments lead to sulfate reduction (carbon reduction is limited because of the large sulfate reserves in marine sediments) and formation of sulfides, which are toxic to higher forms of life. Literature reviews suggest that sulfate reduction, with sulfide as a by-product, becomes a problem when redox potential (E_H) is less than -100 mv. -150 mv seems to be a threshold for the appearance of significant sulfide concentrations (Gambrell, et al., 1976). Some inland water ecosystems, particularly wetlands, are so strongly reduced that reduction of both sulfate (forming sulfides) and carbon (forming methane) are commonplace because of the storage of vast quantities of organic debris. This situation invariably leads to highly reduced environments in wetlands with a distinct rotten egg odor and "swamp gas." Because storage of organic remains is an important natural function of wetlands, they should not be expected to meet a standard for redox potential.

The proposed standard generally parallels the progression of oxidation states described in Stumm and Morgan (1970):

Decreasing redox potential ↓

Sequence of hydrogen acceptors	Redox potential (E_H)
Oxygen (aerobic respiration)	$>+100$ mv
Nitrite- nitrate reduction (forming ammonia)	$<+100$ mv
Sulfate reduction (forming sulfides)	<-100 mv

The standard should be limited to the uppermost 10 cm of sediment because:

1. Most infauna live in the uppermost 10-20 cm of sediment.

2. Microbiological populations are most numerous and most active in the uppermost 5-10 cm of sediment.

3. It is difficult to obtain sediment cores much deeper than 10 cm from some types of bottoms.

The E_H values proposed as thresholds for an interim standard are very tentative, since they are based largely on experience outside Hawaii and local data are very scanty. However, feedback from the monitoring program will provide a firmer empirical basis for future revisions of this standard. Until sufficient local experience accumulates, the redox potential standard should be considered more provisional than standards related to the water column.

NAME OF STANDARD:	Oxidation/Reduction Potential Within Soft Bottoms
PURPOSE OF STANDARD:	To maintain an oxidizing sediment environment in ecosystems which are naturally oxidizing. To maintain a sediment environment in which there is no significant sulfate reduction in ecosystems which are naturally reducing.
STANDARD:	Oxidation/reduction potential (E_H) in the uppermost 10 cm of sediment should not be less than +100 mv in soft bottoms which are not naturally reducing. Oxidation/reduction potential (E_H) in the uppermost 10 cm of sediment should not be less than -100 mv in soft bottoms which are naturally reducing.
GEOGRAPHIC APPLICATION OF STANDARD:	<u>E_H not less than +100 mv</u> Streams (soft substrata) Anchialine pools (soft substrata only) Sand beaches Nearshore reef flats (soft substrata only) Offshore reef flats (soft substrata only) Marine pools (soft substrata in pools which are infrequently renewed with water) Protected coral communities (soft substrata only) Wave exposed reef communities (soft substrata only) Estuaries (stream mouth estuaries shallower than 2m; spring-fed estuaries) <u>E_H not less than -100 mv</u> Soft bottom communities Artificial basins Estuaries (stream mouth estuaries deeper than 2m; developed estuaries)
MONITORING FREQUENCY AND PRIORITIES:	Routine measurement, especially where sediments have the characteristic black color that results from free sulfides reacting with available iron. There should be added emphasis on redox potential in ecosystems where low visibility limits the effectiveness of other bottom indicators of water quality.

LONG-TERM ACCUMULATION OF FINE-GRAIN SEDIMENTS

Rationale for Standard:

Long-term shifts toward smaller grain sizes in sediment environments indicate locations where sediment is depositing faster than it can be reworked and redistributed by waves and currents.

The dependence of benthic organisms on particle size and sorting of sediment is a well-documented relationship (Sanders, 1958). Sediment chemistry is also dependent on particle size, with pollutant potential generally increasing as particle size decreases. Consequently, grain size distribution is a very important physical parameter in understanding sediment environments (Slotta, et al., 1974). The formation of sediment sinks results in a shifting, physically unstable substrata and may promote reducing conditions in the sediment interstitial waters (see standard for oxidation-reduction potential).

Chronic instability at the surface clogs the filtering structures of suspension feeders, discourages the settlement of larvae of suspension-feeding animals, buries newly settled larvae and limits the ability of sessile epifauna to maintain a firm connection with the unstable bottom. The invertebrate populations associated with silt bottoms are invariably dominated by only a few species (Neighbor Island Consultants, 1973).

If a source of fine-grained organic or inorganic material is available, the near-surface sediments may remain in an unconsolidated state, making them more vulnerable to resuspension. Unconsolidated "soupy" sediments also imply a reduction in bearing capacity and increased water content, both of which have been shown to affect the abundance of benthic infauna (Rhoads, 1970; Harrison and Wass, 1975).

Rhoads (1970) has demonstrated that sediment bearing capacity is an important physical property for most benthic infauna. The sediment must be strong enough to support the weight of the animal yet weak enough to permit burrowing. The sediment strength sets a threshold on the weight to surface area ratio of fauna and flora which can be supported near the surface of the sediment. The net effect is that only species of low density or high vertical mobility can survive in such an environment (Slotta, et al., 1974). Heavier animals will sink uncontrollably into the sediment.

The physical reworking of sediments by burrowing infauna tends to modify conditions away from extremes of very fine or very coarse sediments. Bioturbation ventilates and supplies fine organics to very consolidated materials, while conglomerating very fine, unconsolidated materials by ingestion and excretion.

> The net effect of all of these biogenic activities is to moderate extreme conditions within the sediment. That is, medium strength, medium water content and medium grain size appear to be preferred conditions for benthic organisms and bioturbation tends to maintain these conditions within the sediment. (Slotta, et al., 1974).

The detrimental effect of very fine sediment is borne out by experiments in which either the fraction under 0.2 mm or the silt fraction was removed from natural sand, whereupon it became considerably more attractive to benthic infauna than before (Webb, 1958a; Webb, 1958b; Webb and Hill, 1969).

The porosity and "soupiness" of sediment is related to its mechanical structure, particularly to the proportion of particles of 0.2 mm or less (Cox, 1976). The finer the material, the more water it holds. Mixtures of different particle sizes have a lower porosity than any one size separately due to better "packing." Sediments having high water content and low cohesion are more readily entrained and resuspended by water motion than those of low water content.

The importance of particles smaller than 0.2 mm in relation to the consolidation and porosity of sediments suggests that diameter as a threshold for the interim standard. This size corresponds to the most mobile particles in the erosion-transport-deposition cycle.

This standard is intended to complement the standard for episodic deposits of terrigenous sediments. This standard may indicate where sinks are forming because long-term accumulation of sediment exceeds redistribution by waves and currents. Bottom types which act as natural sinks or perform a natural sediment storage function (Soft Bottom Communities, Artificial Basins, Estuaries, Wetlands) are exempted from this standard.

This standard will warn water quality managers of a possible chronic source of sediment input. To aid in "tracking" the problem back to its cause, it is necessary to determine the proportions of the sediment attributable to reef organisms (% calcium carbonate), attributable to detritus associated with dead plankton (% organic content), and the remaining proportion, which is presumably attributable to terrigenous sediment discharges.

NAME OF STANDARD:	Long-Term Accumulation of Fine-Grain Sediments
PURPOSE OF STANDARD:	To maintain physical stability of soft substrata for resident fauna.

STANDARD:	No more than 50% (by weight) of the grain size distribution of any soft bottom should be smaller than 0.2 mm diameter.
GEOGRAPHIC APPLICATION OF STANDARD:	Streams (soft substrata only) Anchialine pools (soft substrata only) Sand beaches Nearshore reef flats (soft substrata only) Offshore reef flats (soft substrata only) Marine pools (soft substrata only) Protected coral communities (soft substrata only) Wave exposed reef communities (soft substrata only)
MONITORING FREQUENCY AND PRIORITIES:	Infrequent monitoring at locations suspected of becoming sediment sinks.

EPISODIC TERRIGENOUS SEDIMENT ACCUMULATION

Rationale for Standard:

Sudden deposits of land-derived sediment falling from above may bury substrata and smother the more vulnerable benthic organisms. Those most susceptible to sudden burial are sessile surface dwellers, slow-moving and weak burrowing infauna and deep-living commensals in the tubes and burrows of other organisms.

It is generally recognized that reef-building corals are extremely sensitive to siltation (Maragos, 1972; Johannes, 1975). Sediment appears to exert a threshold effect on corals (Maragos, 1972) and perhaps other organisms. Corals are capable of surviving continuous low inputs of sediment where the rate of sediment deposition per unit of time is less than the rate of sediment shedding or turnover by the combined efforts of the corals and water motion (Loya, 1976).

Most of the damage done to corals by terrigenous sediment deposition seems to be associated with episodic flood events (Banner, 1968, 1974). It is difficult to isolate the effects of sediment deposition because it is frequently accompanied by a sharp drop in salinity. The combined effects of floods and their sediment loads must be considered in developing a sediment deposition standard because "exposure of reefs to brackish, silt-laden water associated with flood runoff has probably been the single greatest cause of reef destruction historically" (Johannes, 1975).

Most reef-building corals possess some capacity to remove sediments from their surfaces by ciliary actions. This capacity varies according to species, being lowest among corals living on the outer edge of a reef (Vaughan, 1919, Hubbard, 1974). Those at the reef edge are exposed to more water motion which compensates for less self-cleaning ability (Hubbard, 1974).

Corals are "size-specific sediment rejectors," removing smaller, lighter particles more effectively than larger, heavier particles. Thus, the threat posed by sediment deposition varies both with species of coral and sediment size (Hubbard and Pocock, 1972). Large-polyped forms in general appear to remove accumulated sediments better than small-polyped forms (Mayor, 1918). Pocillopora sp. seem to succumb to sediment more readily than others (Edmondson, 1928; Maragos, 1972).

Corals can live for limited periods after having their surfaces covered with silt, but no species will survive when heavily coated or buried beneath sediments (Mayor, 1918, Edmondson, 1928; Marshall and Orr, 1931). Hubbard and Pocock (1972) found that gradual sedimentation had no adverse effect on species of Caribbean reef-building corals but instantaneous burial under 2-3 cm of sand for periods of more than 48 hours was likely to cause death by suffocation. Hawaiian coral species buried under 4 inches of sand and silt by Edmondson (1928) eventually died. Mayor (1918) found that corals inhabiting outer exposed reefs could not survive burial under 2 inches of mud for longer than 14-1/2 hours but corals adapted to inshore protected reefs were still alive after 24 hours beneath the mud. However, such heavy deposits of sediment are unlikely to occur in nature.

Few cases of actual burial of corals by sediments have been reported. Banner (1968, 1974) documented the combined effects of sediment and "freshwater kill" on Kaneohe Bay reefs following a major flood in 1965. The natural smothering of corals on the reef has been noted by Wood-Jones (1907) and UmGrove (1930). In Kaneohe Bay the natural burial of living corals by sediment talus is occurring off the leeward lagoon reef slopes (Maragos, 1972). The actual cause of death from burial is thought to be a by-product of microbiological respiration in the sediment leading to oxygen depletion (Hubbard, 1974).

There is very little quantitative information on which to base an interim sediment deposition standard. There is no evidence that the most sensitive coral species can survive sudden deposits of more than about 2 mm of sediment. In laboratory tests, coral species from the Great Barrier Reef were generally able to survive silt loads amounting to less than 1 mm per day (Marshall and Orr, 1931). However, in situ experiments with Puerto Rican corals showed that a layer of 1.5 mm of sediment caused mortality of sensitive species, while hardy species often removed a 3 mm layer of sediment completely or suffered only a low mortality (Kolehmainen, 1973). Bartram (unpublished) has documented similar responses by corals in mid-Kaneohe Bay using in situ experimental procedures of Kolehmainen. Until more evidence accumulates that sensitive coral species can survive higher loadings, land-derived sediment deposition should be limited to 2 mm per day.

There is very little information on the sediment tolerances of surface-dwelling organisms other than corals. Sediment accumulations of 1/2 inch to 1 inch over normally satisfactory hard substrata appear to be ecologically disruptive to stream bottom life (Ellis, 1936). A limit of 5 mm per day on land-derived sediment deposition is proposed as an interim standard for hard substrata other than living corals until there is evidence that resident fauna can survive higher levels.

Burrowing infauna can obviously tolerate higher rates of sediment deposition than surface-dwellers, but the standard should be set to protect the weakest burrowers. Strong burrowing worms may be able to survive burial under 15 cm of sediment for periods of several days, when small crustaceans and mollusks are killed (Oliver and Slattery, 1976).

Aller and Dodge (1974) using colored sediment layers, measured *in situ* reworking of sediments by infauna. Their results suggest that some kinds of soft bottom infauna can rework 6-7 cm of sediment per week. It is thought that a limit of 10 mm per day on land-derived sediment deposition would protect soft bottom infauna until there is evidence that they can survive higher loads. Of course, this standard does not apply to ecosystems which are natural sinks for sediment such as wetlands, estuaries, soft-bottom communities, and artificial basins. These systems are generally well adapted to high inputs of sediment.

Past experience with damaging rates of sediment deposition suggest that monitoring can be safely limited to the 2-4 heaviest rainfall events each year. Deposits of land-derived sediment may not do much damage if removed quickly by waves and currents or by the animals themselves. Therefore, the standard is expressed in terms of a thickness of sediment *persisting* for a day or longer.

Investigators would measure the thickness of non-calcareous sediment immediately after a flood when evidence of fresh sediment deposits should not be too difficult to detect. Sediment thickness would be an integration of many measurements at several stations, not just at one spot. Twenty-four hours later, investigators would return to the same stations to see if water motion and the animals' efforts to shed or turnover sediment had removed the sudden deposits. Only if the deposits still exceed the threshold after 24 hours is the standard considered to be exceeded.

NAME OF STANDARD:	Episodic Terrigenous Sediment Accumulation
PURPOSE OF STANDARD:	To detect sudden accumulations of terrigenous sediment following heavy rains which, if not removed by wave actions, will bury or smother sessile epifauna and weak-burrowing infauna.
STANDARD:	Sudden deposits of non-calcareous sediment not to exceed a thickness of 2 mm over living coral substrata for longer than 24 hours following a heavy rainstorm.
	Sudden deposits of non-calcareous sediment not to exceed a thickness of 5 mm over other hard substrata (other than living coral surfaces) for longer than 24 hours following a heavy rainstorm.
	Sudden deposits of non-calcareous sediment not to exceed a thickness of 10 mm over soft substrata for longer than 24 hours following a heavy rainstorm.

GEOGRAPHIC APPLICATION OF STANDARD:

Not more than 2 mm non-calcareous sediment cover

Nearshore reef flats (living corals)
Offshore reef flats (living corals)
Protected coral communities (living corals)
Wave exposed reef communities (living corals)

Not more than 5 mm non-calcareous sediment cover

Streams (hard substrata)
Lava rock shorelines
Marine pools (hard substrata)
Calcareous benches
Nearshore reef flats (hard substrata)
Offshore reef flats (hard substrata)
Protected coral communities (hard substrata)
Wave exposed reef communities (hard substrata)
Anchialine pools (hard substrata)

Not more than 10 mm non-calcareous sediment cover

Streams (soft substrata)
Anchialine pools (soft substrata)
Sand beaches
Marine pools (soft substrata)
Nearshore reef flats (soft substrata)
Offshore reef flats (soft substrata)
Protected coral communities (soft substrata)
Wave exposed reef communities (soft substrata)

MONITORING FREQUENCY AND PRIORITIES:

Tied to climatic events, usually immediately following the 2-4 heaviest rainfalls each year. Priority areas for monitoring are protected coral communities where the overlying water column is exposed to perennial or seasonal stream discharges.

ACCUMULATION OF HEAVY METALS/PESTICIDES IN TISSUES OF AQUATIC ORGANISMS

Rationale for Standard:

The effects of heavy metals and pesticides in inland or marine waters are poorly understood. Although some of these effects are fatal to individual organisms, the more important biological effects are sublethal to individual organisms but of major consequences to the species. These effects and their causes are usually difficult to detect until damage is widespread. Chemical substances combining the characteristics of mobility, chemical stability, low solubility in water, high solubility in body fats and the tendency to be fixed in body tissues and not be excreted may be widely dispersed in inland or marine waters, affect many species and be impossible to control, limit in distribution or "manage" once they have been released in the environment (NAS-NAE, 1970). Monitoring discharges of such materials is clearly a second line of defense.

Heavy metals and many of the persistent pesticides are passed through the food chain through accumulation and bioconcentration. The tendency for any pollutant to be biomagnified in marine food chains is dependent on the chemical characteristics of the pollutant and its interaction with the tissues of marine organisms.

Ultimately biomagnification depends on the rates of uptake and release of the pollutant by marine organisms, the nature of the tissue "binding" of the pollutant and finally the availability of ingested tissue-bound pollutants to consumers at higher trophic levels. There is a growing volume of published data on uptake and release rates of various pollutants by many species of marine organisms. However, there is relatively little information about the behavior of pollutants once they are absorbed or adsorbed by the organism. If we are to predict the potential for a given pollutant to biomagnify in the marine food chain, much more information is needed about such subjects as the distribution of pollutants in the tissues of contaminated organisms, the nature of the tissue-pollutant binding and the availability of tissue-bound pollutants to consumers of contaminated organisms.

Uptake at the primary producer level is the most important mechanism for metal transfer into the biosphere and therefore requires considerable further research. The relationship between pollutant uptake and primary production should also be better established. The relative importance of pollutant removal by settling dead phytoplankton cells and fecal pellets should be evaluated in relation to variations in primary and secondary production rates. This may be a major route for transfer among trophic levels since it represents a mechanism for making metals available through the detrital food web (Windom and Duce, 1976). Biomagnification of heavy metals and pesticides through the detrital food web appears to be a particularly important pathway for transfer in embayments.

Whatever the mechanisms for accumulation, many organisms have the capacity to concentrate substances thousands of times more than the concentrations occurring in solution or suspension in the water around them. Analysis of carnivores high in the food chain and other organisms whose feeding habits are known to concentrate heavy metals or pesticides (detrital feeders) are usually more relevant and informative than are analyses of water (NAS-NAE, 1970; Lau, 1975).

Ratios of pesticide concentrations in the waters of the Ala Wai and Kapalama Canals compared to concentrations in the tissues of canal biota illustrate bioconcentration (Bevenue, et al., 1972):

Water	1
Algae	4,300
Sediment (wet weight basis)	9,000
Small fish	27,000
Carnivore fish	33,000
Detrital-feeding fish	36,000

The effects of bioaccumulation have centered largely on the public health aspects of human consumption of edible species. Although there are undoubtedly physiological effects in organisms with high but sub-lethal burdens of heavy metals or pesticides, they are not well enough documented to be the basis for a water quality standard. The initial standard must be met in terms of public health to protect human consumers rather than biological health.

The hazard of some of the more prominent metals (in terms of the danger to human consumers) may be ranked as follows (NAS, 1974):

Decreasing hazard to public health ↓

Mercury

Cadmium

Silver

Nickel

Lead

Arsenic

Chromiun

Tin

Zinc

The organisms selected for tissue analysis should meet four criteria:

1. In order to establish cause-effect relationships with a particular location, they should have a limited habitat and not be wide ranging.

2. They should be species people eat.

3. They should be predators at the top of the food chain or have feeding habits (such as detritus-feeding) which would concentrate chemicals. Higher concentrations of mercury have been reported in the tissues of omnivores and carnivores than herbivores (Klemmer, 1975).

4. They should be the oldest available members of their populations because of longer exposure time to potential toxics.

Appendix A (of the Manual submitted to the Department of Health) is a summary of pesticide residue and mercury measurements made on marine biota collected during the four-year Quality of Coastal Waters Project (Lau, et al., 1973).

NAME OF STANDARD: Heavy Metal/Pesticide Concentrations in Tissues of Edible Fish and Invertebrates.

PURPOSE OF STANDARD: To protect human consumers of fish, invertebrates and algae.

STANDARD: Concentrations of heavy metals/pesticides in the tissues of indicator organisms--especially edible portions--should not exceed safe levels. "Safe levels" for pesticides are those endorsed by the U.S. Environmental Protection Agency for shellfish. (See table on "Recommended Guidelines for Pesticide Levels in Shellfish" on the following page.)

EPA has not yet recommended criteria for safe levels of heavy metals that would protect human consumers.

GEOGRAPHIC APPLICATION OF STANDARD:
Streams (particularly those draining urban and agricultural basins)
Estuaries (stream mouth estuaries and developed estuaries)
Artificial basins
Nearshore reef flats (only in embayments)
Lava rock shorelines (only in embayments)
Any bottom type exposed to thermal effluent from power-generating plants or other industrial waste discharges.

Recommended Guidelines for Pesticide Levels in Shellfish

Pesticide	Concentration in shellfish (ppm--drained weight)
Aldrin	0.20
BHC	0.20
Chlordane	0.03
DDT)	
DDE) ANY ONE OR ALL, NOT TO EXCEED	1.50
DDD)	
Dieldrin	0.20
Endrin	0.20
Heptachlor	0.20
Heptachlor Epoxide	0.20
Lindane	0.20
Methoxychlor	0.20
2,4-D	0.50

It is recommended that if the combined values obtained for Aldrin, Dieldrin, Endrin, Heptachlor and Heptachlor Epoxide exceed 0.20 ppm, such values be considered as "alert" levels which indicate the need for increased sampling until results indicate the levels are receding. It is further recommended that when the combined values for the above have pesticides reach the 0.25 ppm level, the areas be closed until it can be demonstrated that the levels are receding.

U.S. Department of Health, Education and Welfare, Public Health Service 1968.

Source: National Academy of Sciences, National Academy of Engineering, (1974): Water Quality Criteria 1972, EPA-R3-73-C33, Washington, D.C., p. 37.

MONITORING FREQUENCY AND PRIORITIES:	Routine tissue analyses of organisms collected from any ecosystems associated with embayments or exposed to industrial waste discharges.
INDICATOR SPECIES:	Organisms collected for tissue analysis should be the oldest available members of their populations.

Ecosystems	Indicator Organisms	Trophic Level
Streams (draining agricultural or urban watersheds)	I. Fishes	
	Eleotris sandwicensis ('O'opu akupa)	Carnivore
	Awaous stamineus ('O'opu nakea)	Omnivore
	Sicydium stimpsoni ('O'opu nepili)	Herbivore
	Clarius fuscus (Chinese catfish)	Omnivore
	II. Crustaceans	
	Macrobrachium *grandimanus* (Opae 'oeha'a)	Deposit feeder/ Carnivore
	Macrobrachium lar (Tahitian prawn)	Deposit feeder/ Carnivore
	Atya bisulcata (Opae kala'ole)	Suspension feeder
	III. Mollusks	
	Netritina granosa (Hihiwai, wi)	Herbivore
Estuaries	I. Fishes	
	Mugil cephalus (Mullet)	Herbivore
	Kuhlia sandvicensis (Aholehole)	Omnivore

INDICATOR SPECIES (continued):	Ecosystem	Indicator Organisms	Trophic Level
	Estuaries (cont.)	Sphaeryna barracuda (Barracuda)	Carnivore
		II. Crustaceans	
		Scylla serrata (Samoan crab)	Deposit feeder/ Omnivore
		Portunus sanguinoletus (haole crab)	Deposit feeder/ Omnivore
		Thalamita crenata (blue claw crab)	Deposit feeder/ Omnivore
		III. Algae	Primary producers
		Enteromorpha flexuosa (limu 'ele'ele)	
		Gracilaria bursapastoris (ogo)	
		Gracilaria coronopifolia (limu manauea)	
		Hypnea cervicornis (limu huna)	
		Ulva fasciata (limu papahapaha)	
	Artificial Basins	I. Fishes	
		Stolephorus purpureus (nehu)	Plantivore
		Pranesus insularum (iao)	Plantivore

INDICATOR SPECIES (continued):	Ecosystem	Indicator Organisms	Trophic Level
	Artificial Basins (cont.)	II. Crustaceans	
		Portunus sanguinoletus (haole crab)	Deposit feeder/ Omnivore
		Grapsus grapsus (rock crab)	Deposit feeder/ Omnivore
		III. Algae	Primary producers
		Enteromorpha flexuosa (limu 'ele'ele)	
		Gracilaria bursapastoris (ogo)	
		Hypnea cervicornis (limu huna)	
		Ulva fasciata (lima papahapaha)	
	Lava Rock Shorelines Associated with embayments (with freshwater seepage)	I. Mollusks	
		Ostrea sandvicensis (Hawaiian oyster)	Suspension feeder
		Isognomon californicum (clam)	Suspension feeder
		II. Algae	Primary producers
		Ahnfeltia concinna (limu 'aki'aki)	
		Asparagopsis taxiformis (limu kohu)	
		Enteromorpha flexuosa (limu 'ele'ele)	

INDICATOR SPECIES (continued):	Ecosystem	Indicator Organisms	Trophic Level
	Lava Rock Shorelines Associated with embayments (continued)	Grateloupia filicina (limu huluhuluwaena)	
		Laurencia nidifica (limu lip'epe'e)	
		Laurencia succisa (lima mane'one'o)	
		Sargassum echinocarpum (limu kala)	
		Ulva fasciata (limu papahapaha)	
	Lava Rock Shorelines Associated with Embayments (without fresh-water seepage)	I. Mollusks	
		Nerita picea (pipipi)	Herbivore
		Isognomon incisum (clam)	Suspension feeder
		II. Algae	Primary producers
		Ahnfeltia concinna (limu 'aki'aki)	
		Asparagopsis taxiformis (limu kohu)	
		Enteromorpha flexuosa (limu 'ele'ele)	
		Grateloupia filicina (limu huluhuluwaena)	
		Laurencia nidifica (limu lipe'epe'e)	
		Laurencia succisa (limu mane'one'o)	

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INDICATOR SPECIES (continued):	Ecosystem	Indicator Organisms	Trophic Level
	Lava Rock Shorelines Associated with Embayments (without freshwater seepage) (cont.)	*Sargassum echinocarpum* (limu kala) *Ulva fasciata* (limu papahapaha)	
	Any bottom type exposed to industrial waste discharges	Characteristic algae, crustaceans, mollusks and fishes	

GENERAL DISCUSSION OF BIOLOGICAL INDICATORS

It is generally preferable to infer biological responses on the basis of physical-chemical proxies than to measure them directly, because physical-chemical analyses are usually easier to perform, more accurate and precise. For some purposes, however, living systems are more sensitive than human instrumentation and may indicate the results of biological responses that cannot be directly perceived. All organisms are to some degree indicators of their environment. "Indicator species" are groups of organisms which are so sensitive to their environmental surroundings that their responses to environmental changes provide a direct measure of biological effects rather than having to infer them on the basis of physical-chemical measurements. The value of biological monitoring as part of programs to detect and document change in the quality of aquatic environments has long been recognized (Hynes, 1960; Sladecek, 1973).

Biological indicators may detect three types of changes:

(1) Changes that alter the proportionate representation of species;

(2) Changes that alter the quality of the species represented (fast versus slow growers; specialists versus generalists).

(3) Changes that alter the developmental stage of a community within the framework of ecological succession. Changes not predicted by the general direction of succession may provide evidence of water quality problems.

Increasing the understanding and predictability of the patterns of community succession will increase scientists' ability to interpret changes that do not appear to follow the normal sequence of succession and may be attributed to man-induced disruptions.

The use of bottom-living organisms as water quality indicators rests on the assumption that we know enough about the usual environmental relationships of particular organisms, or about community structure in general, to associate differences in the composition and structure of benthic assemblages with differences in their physical-chemical surroundings.

The difficulty is to differentiate changes in biological structure induced by man-made perturbations from those occurring naturally. Ecosystems may change with the time of day, season of the year, and from year to year. Natural fluctuations may behave as "noise" in the system obscuring the "signal" representing biological responses to pollutants (Eberhardt, 1975).

The identification of a "significant" change in biological structure assumes that a commonly accepted norm exists against which to measure change. Therefore, biological standards require a baseline - a determination of what is normal. The essential attribute of a baseline survey is that it be representative of conditions in a given place at a particular time. The time and effort involved in establishing a baseline varies with the indicators being used. Spatial and temporal "patchiness" is typical of benthic communities. If the survey area is too small or the time period is too short, the results do not serve as a legitimate baseline. One survey might be sufficient for relatively long-lived species, while several surveys might be required for short-lived species which are subject to seasonal variations in recruitment or mortality. It might take several years to establish an adequate baseline in some instances.

> It is obvious, then, that temporal variation must be taken into account when comparing benthic data from different localities and also when making comparisons over time for a particular area. Somewhat surprisingly, seasonal effects are often ignored in choosing sampling dates and this negligence may often have implications for the assessment of environmental quality or for the detection of change. (Howmiller, 1975)

Seasonal variations make it imperative to conduct comparative surveys at the same time of the year and thus eliminate season as a variable when comparing benthic assemblages between years or from place to place.

Spatial variability from station to station is often substantial. Since water quality investigators are usually interested in a large area, rather than a particular spot, increasing the number of stations in an area will allow investigators to escape some of the effects of spatial patchiness (Howmiller, 1975).

After a satisfactory baseline is established, monitoring surveys, repeated at selected intervals, generate continuing serialized "snapshots" of community structure which can be compared to the baseline and to one another. An aberrant or abnormal change in one or more structural characteristics is interpreted as evidence of pollutional stress.

Abnormal changes may often go unnoticed because what is "normal" is not well understood. Changes less than 50% often may not be detectable against a background of natural fluctuations. Therefore, biological standards should be expressed as changes from baseline conditions which are large enough that they are certain to be detectable and cannot be attributed to natural fluctuations. Changes large enough to exceed the standard should place an area on "red alert" status. "Red alert" status should initiate an intensive search for probable causes of the problem. Although the "red alert" forms the basis for a standard, more subtle shifts in biological structure may attract attention during monitoring surveys. These should be considered "yellow alert" level changes. If they are statistically significant (at the .05 confidence level), they require an explanation. The explanation may be that the shift was part of a natural cycle or attributable to unusual weather conditions. Where obvious shifts in structure occur but are not large enough to exceed the standard, an area should be placed on "yellow alert" status until the shifts can be explained. "Yellow alert" status warrants increasing routine monitoring of the water column.

It may be argued that very subtle changes may be occurring which completely escape attention. However, if we cannot detect them, the most subtle changes cannot be scientifically evaluated. This is a major limitation of water quality standards in general, and of bottom-related standards in particular.

> It is tempting to assume that a major change in community structure will inevitably be accompanied by a change in community function, but the evidence to support this assumption is very scanty. Functional attributes of an aquatic community such as nutrient transfer, energy dissipation, various rate processes, and the like may or may not accompany changes in community structure. It is possible that a significant shift in diversity may cause no functional alterations, because community metabolism may have homeostatic mechanisms capable of adjusting to the loss of some species or readjustment of numbers of individuals per species or both. On the other hand, it may be possible to alter community function without changing community structure at all. There is ample evidence that one can alter the function of individual organisms without killing or eliminating them; and if this is possible for community components, it seems reasonable that it may apply to communities as well. The relationship between community structure and function is one of the badly neglected areas of pollution ecology. (Cairns, 1977)

There are other problems with associating changes in biological structure with pollution:

-Changes in biological structure do not indicate exact causes.

-Biological responses may not be in direct proportion to concentrations of pollutants. Threshold effects may obscure the presence of pollutants or delay their effects.

-The nature of the response may be species dependent and vary greatly among species. Ecotypic and genetic variation within species may also vary.

-Since investigators cannot usually look at all plants and animals, they must rely on indicator organisms, and may select the wrong ones for study.

-It is unlikely that anything but quite sizeable changes in benthic biological structure will be detected.

-The results of benthic biological surveys are less transferrable to other areas than the results of water column physical/chemical analyses.

Despite several limitations, biological composition of benthic assemblages can play three useful roles in monitoring long-term changes in water quality:

(1) To detect and document changes in benthic assemblages over time at specific locations with high natural quality worthy of preservation. Time series benthic surveys may detect deviations from normal successional progression of the ecosystem that are not otherwise obvious.

(2) To search for evidence of changes in biological structure at specific locations over a period during which there has been suspected pollutional stress on the ecosystem ("before-and-after" comparative surveys).

(3) To determine if benthic assemblages of perturbed areas are returning to their pre-disturbance biological structure or if the return to pre-disturbance structure is retarded by residual or persistent pollution.

Many different diversity indices have been proposed and uncritically applied as measures of ecological health. Although the number of species represented in a benthic community is important, numerical indices of diversity summarize community structure in a single value without respect to its composition. They are determined largely by the more abundant species and little affected by the rarer ones. As summaries, they lose information concerning the identity of the species involved and may be insensitive to major changes in species composition. Investigators often fail to take full advantage of the store of information represented by benthic community structure and species composition.

> We cannot have a sensible and sensitive index without taking into account the composition of the assemblage of organisms and their ecological attributes. (Howmiller, 1975)

Investigators should rely on a primary set of organisms that are expected to be sensitive indicators of benthic biological organization. However, they should also be watchful of unexpected changes in biological structure and composition which may not show up in primary indicators but are expressed in terms of other organisms.

Without time series surveys, it is difficult to associate differences in biological structure with changes in water quality, even in highly perturbed ecosystems. For example, a thorough biological study of Pearl Harbor concluded that present environmental insults were masked by "...the inherent variability found in any ecosystem" (Evans, et al., 1974).

Benthic time-series surveys cannot be conducted at nearly as many locations as water column monitoring. Therefore, target areas for benthic biological surveys should be selected with care. All benthic survey areas should be coordinated with water column monitoring stations and should be permanently marked with stakes or other devices so that they can be precisely relocated.

Standardized photo-transects should be made in conjunction with visual surveys of corals and other hard bottom invertebrates, and macroalgae. The photography is a simple method of documenting large amounts of information in some ecosystems and provides a permanent record of the larger surface-dwelling benthic assemblages at the time of the survey.

No single approach or group of indicator organisms is appropriate for all bottom types. A whole battery of methods is needed to cover all the possibilities. Some indicator organisms are best expressed in terms of areal coverage; others in terms of biomass; and still others in terms of number of individuals.

Corals

Corals are best expressed in terms of areal coverage or percent cover of a standard area. Encrusting forms of sponges, colonial tunicates, and bryzoans are also easiest to measure as areal coverage.

Benthic Algae

Algae may be measured in terms of areal coverage or biomass. It is thought that biomass is a more meaningful index.

Surface-dwelling Macroinvertebrates

Hard substrata (solid reef, basalt rock) are often dominated by surface-dwelling invertebrates. Invertebrates generally larger than 3 centimeters in some dimension may be visually censured without disturbing the substratum. Invertebrates other than corals, encrusting sponges, colonial tunicates, and bryzoans may be expressed as number of individuals per standard area or as biomass. There are a number of difficulties in defining biomass, so number of individuals per standard area is preferred. The standard area is usually one square meter.

Infaunal Macroinvertebrates

Infaunal invertebrates dominate bottoms of sand or silt. They may be censused as number of individuals per volume of material obtained by excavating a prescribed depth of a prescribed area of bottom. The usual depth of excavation is 10-20 centimeters, because most infauna do not live deeper. The usual area excavated is one-quarter meter. Organisms larger than 0.5 mm in some dimension are usually considered macroinvertebrates. This excludes meiofauna which live in the interstices of sediment.

Epifaunal and Infaunal Macroinvertebrates

Rubble or broken limestone bottoms may be inhabited by macroinvertebrates with both epifaunal and infaunal habits. Counts of the number of individuals requires excavation of a standard volume of material from the bottom. The material is then chipped down to sediment size, and macroinvertebrates are counted. Because this is a very time consuming procedure, a smaller area (such as 1/8 square meter or less) may be excavated to a depth of 10-20 cm. Biomass may be obtained by weighing all individuals, weighing a representative number of individuals and extrapolating to the rest, or by submitting the entire sample to an acid dissolution process by the method of Brock and Brock (1977). The advantage of the latter method is that reef rock fragments do not have to be chipped away by hand.

Reef Fish

Number of individuals of each species are counted using standardized, accurate, and precise transect methods. Biomass may be estimated from number of individuals by recording the length of fish censused and using standard length-biomass conversion factors for various species.

All of the preceding methods are options which investigators should consider for each survey area. Some of the options may be obviously inapplicable from the outset and eliminated before field work begins. Others may be found to be inadequate after field work commences due to some unanticipated factor. Investigators should use intuitive judgment to select the appropriate method for a given area, and should be flexible enough to substitute methods if the pre-selected one is not working.

There is danger in using only one type of organism or one method to indicate change, so the benthic biological standards provide several options, not all of which are appropriate for a given bottom type.

To be of practical value for management, benthic biological surveys must be relatively crude and sacrifice some of the insight of community dynamics gained in pure scientific research. It may be argued that standards, as expressed in this paper, are insufficient to diagnose or explain why changes have occurred in particular benthic communities of interest. If a water quality problem should warrant extensive analysis of community dynamics (such as a before-and-after sewage relaxation comparison of Kaneohe Bay), there are several analytical tools available or in the research and development stages. A few of these are summarized below with reference to Hawaiian applications of the methodologies:

- Transplanting portions of benthic communities from areas of greater environmental stability to areas of lesser stability and comparing rates of survival and growth (Maragos, 1972, 1974: Corals).

- Monitoring sediment-water recycling of nutrients in situ using sealed bottom domes or bell jars (Smith, et. al., 1977).

- Transplanting portions of benthic communities to special holding systems or microcosms with controlled conditions and monitoring survival in simulated environments different from natural surroundings (Evans and Henderson, 1976: Soft bottom infauna; Evans, 1976: Fouling panel communities).

- Carbon: nitrogen ratios indicating the progression of organic decomposition in organic-rich sediment bottoms (Kroopnick, Personal communication).

- Settling of larvae (reproduction and recruitment) of fouling organisms on standardized racks, panels, or jars over known exposure times (McVey, 1970).

- Species composition, standing crop, relationship to substratum, and trophic structure of micromollusk assemblages (Kay, 1975a, 1975b, 1977a, 1977b).

- Species composition, abundance, and relationship to substratum of foraminifera assemblages (URS Research Company, 1973).

LONG-TERM TRENDS IN REEF-BUILDING CORALS

Rationale for Standard

Reef-building corals are advantageous as water quality indicators to the point of being nearly ideal. Corals are sessile and long-lived, and therefore should integrate water quality changes which occur in one place over long periods of time. Corals have other advantages:

- They have growth rings similar to trees and their growth history is therefore stored and possible to interpret.

- They display a full range of sensitivity to environmental factors.

- They are common in many marine ecosystems, easy to collect, manipulate, and measure.

- They can be photographed.

- Their form, color, size, and growth rate, as well as survival, may indicate long-term trends in water quality.

Similar to the function of trees in land ecosystems, corals provide physical structure for many other organisms. Corals are characterized by high area to volume ratios of living tissue, which means they are fairly exposed to their surrounding environment. Branching type corals appear to be particularly sensitive (Johannes, 1975).

> So central are corals to the integrity of the reef community that when they are selectively killed, migration or death of much of the other reef fauna ensues. Therefore the environmental tolerances of the reef community as a whole cannot exceed those of its corals. Accordingly, our knowledge of the environmental limits of corals can provide us with convenient preliminary criteria for setting standards of environmental quality for reef communities. In instances where other vital components of the reef community prove to have significantly narrower stress tolerances, such regulations would, of course, prove inadequate. (Johannes, 1975)

NAME OF STANDARD: Long-Term Trends in Reef-Building Corals

PURPOSE OF STANDARD: To detect and document shifts in the coral coverage and coral species composition over time in selected areas resulting from the integrated effects of the physical/chemical environment.

STANDARD: Baseline surveys should record the living coral coverage of each reef-building species at selected areas. During repeat surveys, living coral coverage (all species lumped) should not be reduced by more than 50% from the baseline value.

In addition, branching type corals (Porites compressa, Pocillopora, spp.) known to be most sensitive to changes in water quality should not move down the alphabet from their baseline position on the relative scale below in terms of their proportionate contribution to total coral coverage in the survey area.

Scale

A = species accounts for more than 75% of total coral coverage in survey area and is found at all individual stations to the exclusion of other species.

B = species accounts for up to 75% of total coral coverage in survey area and is found in abundance at most individual stations.

C = species accounts for up to 25% of total coral coverage in survey area and is found in localized concentrations at a few individual stations.

D = species accounts for up to 5% of total coral coverage in survey area and is found at a few individual stations.

GEOGRAPHIC APPLICATION OF STANDARD:
Nearshore reef flats (hard substrata only)
Offshore reef flats (hard substrata only)
Protected coral communities (hard substrata only)
Wave exposed reef communities (hard substrata only)

MONITORING FREQUENCY AND PRIORITIES: Annual monitoring surveys at permanent benchmark areas.

"Before-and-after" comparison surveys in areas where perturbations are planned.

(It will be convenient to monitor encrusting forms of sponges, colonial tunicates, and bryzoans, as well as reef-building corals. The abundance of all these fauna are easiest to express as % cover of an area. Sponges and tunicates may replace corals on hard substrata in polluted areas, and so may help to explain shifts in coral coverage.)

Wherever shifts in coral coverage or species composition exceed the standard, an intensive investigation of probable cause should be undertaken to track the problem back to its source.

Repeat surveys may detect statistically significant shifts in coral cover which are not large enough to exceed the standard. These more subtle changes require an explanation and may justify increased water column or benthic monitoring for interpretation.

INDICATOR SPECIES: See Appendix B of manual submitted to Department of Health.

Refer to "Reef and Shore Fauna of Hawaii, Section 1: Protozoa through Ctenophora" (1977) for information on sponge and coral species.

LONG-TERM TRENDS IN MARINE BENTHIC ALGAE

Rationale for Standard

Pollution of marine ecosystems may be reflected in the presence, absence, abundance or biomass of algal indicator species. On a larger scale, pollution may produce changes in algal community species diversity. Pollution effects may be assessed through chemical analysis of the water column (see water column standard for chlorophyll a), bioassay or tissue analysis of algae (see standard for heavy metal/ pesticide concentrations in tissues of edible organisms), or field sampling.

Increase in nutrient levels have been reported to cause increases in algal biomass or changes in community composition of phytoplankton, benthic diatoms, microphytes, macrophytes, crustose and erect coralline algae and algal epiphytes. This standard is concerned with field sampling of shifts in benthic algae patterns over time which might indicate long-term trends in water quality degradation.

Although increased growth of benthic algae is sometimes evidence of advancing euthrophication, there are several problems with algal indicators of pollution:

- There may be high production of benthic algae, but low standing crops because of cropping by herbivores. Cropping - particularly by herbivorous fish - plays an important role in controlling algal growth. Increased fishing pressure by man may decrease fish harvesting of algae and increase standing crops.

- Because benthic algal patterns are subject to seasonal variations, it is difficult to establish what is typical for an area. The species composition of an algal community can be ephemeral. Without continued sampling at intervals separated in time, one cannot judge the successional stage or stability of an observed algal assemblage.

- A time lag often occurs before the onset of increased growth or species change of algae can be detected. Therefore, eutrophication may be fairly advanced before becoming apparent in the algal component of an area. Use of several algal growth forms (i.e., microphytes, macrophytes, and crustose forms) would be the most sensitive indicator of change.

To overcome some of these limitations, a standard should focus on year-long seasonality and growth of the algal component in selected baseline areas. Changes in baseline patterns could then be detected through obvious shifts (> 50%) in the algal component and associated changes in the column indicating eutrophication.

NAME OF STANDARD:	Long-Term Trends in Marine Benthic Algae
PURPOSE OF STANDARD:	To detect and document shifts in benthic algal patterns and algal species composition over time in selected areas resulting from the integrated effects of the physical/chemical environment.
STANDARD:	Baseline surveys should record benthic algal coverage and biomass of microphytic, macrophytic and crustose algae. During repeat surveys, biomass should not increase by more than 50% during annual cycles.

In addition, known indicator species (i.e., *Ulva*, spp., *Enteromorpha*, spp., and *Acanthophora spicifera*) associated with changes in water quality should not move down the alphabet from their baseline position on the relative scale below in terms of their proportionate contribution to total benthic algal biomass in the survey area.

Scale

A = species accounts for up to 25% of total benthic algal biomass in survey area during certain seasons and is not found at all individual stations.

B = species accounts for up to 50% of total benthic algal biomass in survey area during certain seasons, and is found at most individual stations, with high concentrations at a few.

C = species accounts for up to 75% of total benthic algal biomass in survey area during certain seasons and is found in abundance at all individual stations.

D = species accounts for up to 100% of total benthic algal biomass in survey area during certain seasons and is found at all individual stations to the exclusion of other species.

GEOGRAPHIC APPLICATION OF STANDARD:

Lava rock shoreline
Solution benches
Nearshore reef flats
Offshore reef flats
Protected coral communities
Wave exposed reef communities
Artificial basins

MONITORING FREQUENCY AND PRIORITIES:	Monthly monitoring surveys at permanent benchmark areas. "Before-and-after" comparison surveys in areas where perturbations are planned. Wherever shifts in benthic algal biomass or species composition exceed the standard, an intensive investigation of probable cause should be undertaken to track the problem back to its source. Repeat surveys may detect statistically significant shifts in benthic algal biomass which are not large enough to exceed the standard. These more subtle changes require an explanation and may justify increased water column or benthic monitoring for interpretation.
INDICATOR SPECIES:	See Appendix C of manual submitted to Department of Health.

LONG-TERM TRENDS IN MARINE MACROINVERTEBRATES (OTHER THAN CORALS)

Rationale for Standard

The special characteristics that make the larger benthic invertebrates valuable indicators of environmental conditions have been amply discussed (Hynes, 1960, 1964; Reish, 1973). The main concern has been the relationship of invertebrates to various types of substratum (Parker, 1975). However, grouping of marine invertebrates by feeding habit may provide a particularly meaningful index of changing water quality (Guinther and Bowers, 1975).

A balanced benthic community with good water quality might be expected to be dominated by grazing herbivores. Increasing dominance of such a community either by suspension-feeding invertebrates, taking advantage of the higher plankton content of overlying waters; or by deposit-feeding invertebrates, taking advantage of higher organic content of the bottom, are obvious indications of eutrophication.

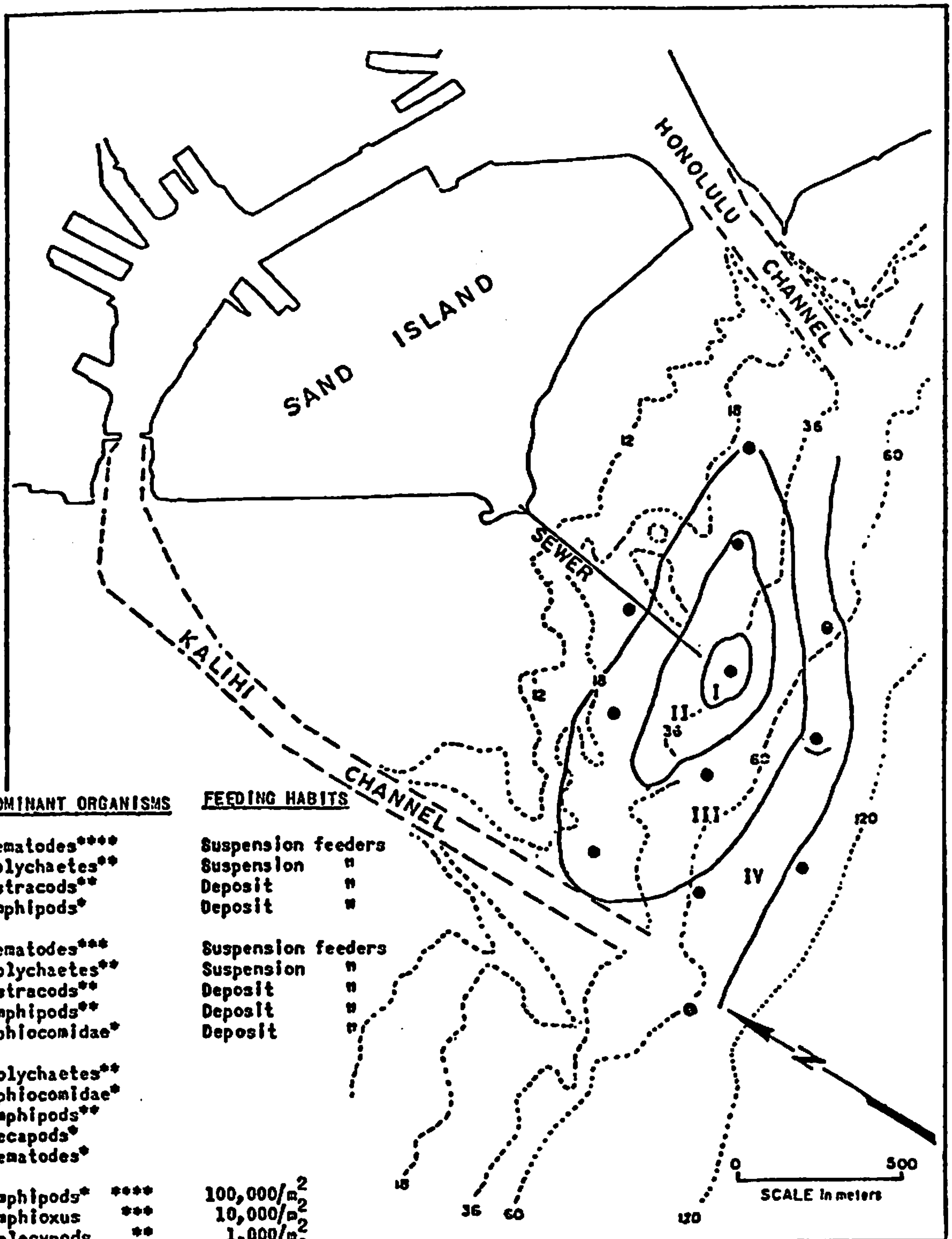
Sponges appear to increase in response to particulate organic enrichment. Dong, et al. (1972) noted that sponge abundance increased with proximity to a sewage outfall in Christiansted Harbor, St. Croix. Burm and Morris (1971) found an increase in sponge density in the vicinity of a sugar mill waste outfall in Hawaii. Banner (1974) noted the dominance of suspension-feeding invertebrates, including sponges and tunicates, in the euthrophic waters of South Kaneohe Bay.

Polychaete worms were observed to be indicators of high organic pollution by Wade, et al. (1972) in Kingston Harbor, Jamaica, and by McNulty (1970) in Biscayne Bay. Brock and Brock (1976) found that polychaetes accounted for a higher proportion of reef rock infauna biomass in the more nutrient enriched portions of Kaneohe Bay. As a group, polychaetes are tolerant of pollution (Kitamori, 1972; Van Middelem, et al., 1972; Reish, 1973).

The presence of significant portions of organic matter, the mechanical nature of sediments, and infaunal feeding habits exhibited a rather close relationship in studies by Sanders (1956, 1958), by McNulty, et al., (1962), and by Brett as noted by Carricker (1967).

The dominant groups of benthic invertebrates in the immediate vicinity of the Sand Island (Oahu) sewage outfall are nematode worms - suspension feeders which subsist on the organics in the outfall solids (City and County of Honolulu Department of Public Works, 1970). Suspension-feeding polychaete worms and deposit-feeding ostracods are also abundant. There appear to be definite gradients in the feeding groups represented in the vicinity of the outfall, as seen in Figure 2.

Because of the apparent correlation of suspension-feeders and



ZONE	DOMINANT ORGANISMS	FEEDING HABITS
I	Nematodes****	Suspension feeders
	Polychaetes**	Suspension "
	Ostracods**	Deposit "
	Amphipods*	Deposit "
II	Nematodes***	Suspension feeders
	Polychaetes**	Suspension "
	Ostracods**	Deposit "
	Amphipods**	Deposit "
	Ophiocomidae*	Deposit "
III	Polychaetes**	
	Ophiocomidae*	
	Amphipods**	
	Decapods*	
	Nematodes*	
IV	Amphipods*	**** 100,000/m^2
	Amphioxus	*** 10,000/m^2
	Pelecypods	** 1,000/m^2
	Polychaetes	* 100/m^2
	Decapods	

Ref: City and County of Honolulu, 1970

Figure 2. Dominant Benthic Invertebrates at the Sand Island Outfall

deposit feeders with water quality degradation, the proposed standard is concerned with the increasing dominance of benthic invertebrate assemblages by these two feeding groups.

NAME OF STANDARD: Long-Term Trends in Marine Macroinvertebrates (Excluding Corals Encrusting Sponges, Colonial Tunicates, Bryzoans)

PURPOSE OF STANDARD: To detect and document shifts in marine macroinvertebrate feeding habits over time in selected areas resulting from the integrated effects of the physical/chemical environment.

STANDARD: Baseline surveys should record the number of individuals of each invertebrate species larger than 0.5mm in some dimension, (excluding corals, encrusting sponges, colonial tunicates, bryzoans) using a variety of methods (see general discussion of biological indicators).

The invertebrate counts should be grouped by feeding groups: grazing herbivores, suspension feeders, deposit feeders, carnivores to establish the baseline position on the scale below.

During repeat surveys, the invertebrate assemblage (excluding corals, encrusting sponges, colonial tunicates, bryzoans) should not move down the alphabet from its baseline position on the scale below.

Scale

A = the majority (>50%) of macroinvertebrates are grazing herbivores.

B = macroinvertebrates are a mixture of grazing herbivores and suspension feeders/deposit feeders/ omnivores. Neither group accounts for more than 50% of macroinvertebrates.

C = the majority of macroinvertebrates (>50%) are suspension feeders/ deposit feeders/ omnivores.

GEOGRAPHIC APPLICATION OF STANDARD:

Marine pools
Solution benches
Lava rock shorelines
Wave exposed reef communities
Protected coral communities
Nearshore reef flats

Offshore reef flats
Soft bottom communities
Artificial basins

MONITORING FREQUENCY AND PRIORITIES:	Annual monitoring surveys at permanent benchmark areas. "Before-and-after" comparison surveys in areas where perturbations are planned. Wherever shifts in marine macroinvertebrate feeding groups exceed the standard, an intensive investigation of probable cause should be undertaken to track the problem back to its source. Repeat surveys may detect statistically significant shifts in macroinvertebrate assemblages which are not large enough to exceed the standard. These more subtle changes require an explanation and may justify increased water column or benthic monitoring for interpretation.
INDICATOR SPECIES:	See Appendix D of manual submitted to Department of Health.

LONG-TERM TRENDS IN REEF FISH

Rationale for Standard

Fish are motile and therefore are not as sensitive indicators of water quality changes as sessile organisms. However, fish are probably the most important herbivores, and fish avoidance or absence in itself can have water quality implications. For example, the degree of fish cropping of Dicytosphaeria cavernosa in Kaneohe Bay has been shown to be an important factor in the abundance and distribution of the green bubble algae (Banner, 1974).

The diversity and abundance of reef fishes has been shown to correlate positively with topographic relief. Areas of greater substratum complexity provide more shelter, feeding, and spawning sites than found on featureless bottoms. In flourishing biogenic reef ecosystems, much of the vertical relief results from coral growth. Therefore, in coral-rich ecosystems, reef fish are a significant component of the biomass. Protected coral communities on leeward coasts and in lagoons harbor a particularly diverse and abundant fish fauna.

Most reef fish may be treated as part of the benthic community, although the degree of association with the bottom is stronger for some species than for others. In ecosystems with high vertical relief, reef fish are sufficiently abundant that sudden shifts in the most numerous species would signal a major change.

Therefore, baseline surveys should census the reef fish populations of selected areas and determine the most numerous species (the ones which account for more than 50% of the total count of reef fish). Repeat surveys should be watchful of major shifts in the abundance of the most numerous species.

As with other indicators, surveys should not be based on too small an area. Monitoring requires the use of standardized, accurate (and precise) transecting methods (Nolan and Taylor, unpublished) over a fairly large area (500 square meters).

NAME OF STANDARD: Long-Term Trends in Reef Fish

PURPOSE OF STANDARD: To detect and document shifts in the most abundant reef fish populations over time in selected areas resulting from the integrated effects of the physical/chemical environment.

STANDARD: Baseline surveys employing standardized, precise, and accurate transect methods should record the number of individuals of all reef fish species over a large area (500 square meters). The species which account for more than half of the total count of reef fish should be identified.

During repeat surveys, the combined abundance of the most numerous species (those which account for more than half of the baseline census) should not decrease by more than 50%.

GEOGRAPHIC APPLICATION OF STANDARD:	Protected coral communities Wave exposed reef communities Marine pools and protected coves Offshore reef flats
MONITORING FREQUENCY AND PRIORITIES:	Annual monitoring surveys at permanent benchmark areas. "Before-and-after" comparison surveys in areas where perturbations are planned. Wherever shifts in the abundance of the most numerous reef fish species exceed the standard, an intensive investigation of probable cause should be undertaken to track the problem back to its source. Repeat surveys may detect statistically significant shifts of reef fish abundance which are not large enough to exceed the standard. These more subtle changes require an explanation and may justify increased water column or benthic monitoring for interpretation.
INDICATOR SPECIES:	See Appendix E of manual submitted to Department of Health.

LONG-TERM TRENDS IN STREAM NATIVE MACROFAUNA

Rationale for Standard

Man-induced changes of streams (channel modification, diversion and dewatering, and introduction of exotic species) influence the occurrence and abundance of native stream animals (Timbol and Maciolek, 1976). Channel modifications and diversion have had their most severe effects at lower elevations because all larger native stream species are diadromous (marine larval development) and the lower reaches of streams are the essential migratory pathways for both seaward-moving larvae and returning juveniles inhabiting upper reaches. Therefore, the presence and abundance of the larger native species in the lower reaches of streams should give a long-term indication of overall stream quality.

Fishes, decapod crustaceans, and the mollusk *Neritina granosa* (hihiwai, wi) are the best indicators because they are the most representative groups of larger native stream animals, relatively conspicuous, and easiest to collect, identify, and observe.

NAME OF STANDARD: Long-Term Trends in Stream Native Macrofauna

PURPOSE OF STANDARD: To detect and document shifts in the representation and abundance of native stream macrofauna over time in selected areas resulting from the integrated effects of the physical/chemical environment.

STANDARD: Baseline surveys should record the occurrence and relative abundance of native species of fish, crustaceans, and mollusks. During repeat surveys, the relative abundance of native stream animals should not move down the alphabet from their baseline position on the relative scale below.

Scale

A = species abundant. Many specimens (≥ 6) obtained each time a collection is made.

B = species common but not abundant. Specimens obtained every time a collection is made but not in abundance (2-5 specimens per collection).

C = species rare/occasional. Only one specimen collected or sighted in at least a 20 meter length of stream.

D = species absent. Not collected or sighted.

GEOGRAPHIC APPLICATION OF STANDARD:	Streams
MONITORING FREQUENCY AND PRIORITIES:	Annual monitoring surveys at permanent benchmark areas. "Before-and-after" comparison surveys in areas where perturbations are planned. Wherever shifts in native stream animal representation and abundance exceed the standard, an intensive investigation of probable cause should be undertaken to track the problem back to its source.
INDICATOR SPECIES:	Native Crustaceans *Atya bisulcata* (opae kalaole) *Macrobrachium grandimanus* (opae oeha'a) Native Mollusk *Neritina granosa* (hihiwai, wi) Native Fish *Awaous genivittatus* *Awaous stamineus* (o'opu nakea) *Eleotris sandwicensis* (o'opu akupa) *Kuhlia sandvicensis* (aholehole) *Sicydium stimpsoni* (o'opu nopili) *Lentipes concolor* (o'opu alamo'o)

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APPENDIX 4

JUSTIFICATION FOR PROPOSED WATER QUALITY STANDARDS INLAND WATERS

The proposed standards for inland waters are based on analysis of existing data. Numerical values are developed mainly for streams where the information base is considered to be strongest. Data from monthly samples collected over a period of two years from selected streams on the islands of Kauai, Oahu, Maui, Molokai, and Hawaii were used for the evaluation. In cases where there are little existing data, the numerical values are estimated based on the best judgment of the committee members, or as a last resort on the U. S. Environmental Protection Agency's recommended guidelines.

Detailed standards were not developed for many of the inland water subtypes because of inadequate data from Hawaii. A systematic sampling program is needed to collect data to strengthen the existing data base, and to establish a firm basis for expanding the entire set of proposed standards.

Selection of water quality parameters for the proposed standards is guided by the ecosystem approach. The proposed list does not represent the all-inclusive parameters for public health, and some aesthetic considerations. The list represents only those substances occuring in water which may have potential harm to aquatic life or to water users. Omissions from the proposed list, however, should not be construed that an omitted parameter is either unimportant or non-hazardous. The criteria for selecting the water quality parameters are that they must be ecologically significant, and they can provide pertinent information to characterize Hawaii's inland-water ecosystem in terms of variation and water quality changes. The parameters should be easily measured and they should be sensitive to small changes such that they can be good indicators of water quality problems, or the lack of such problems.

NUTRIENTS

Nitrogen and phosphorus are essential nutrients for plant growth. They are, in fact, often considered to be the "limiting factors" in primary production. The concentration of soluble inorganic nutrients, namely, ammonia, nitrate, nitrite, and phosphate are generally low in natural freshwater. Surface water bodies that receive sewage effluent, industrial wastes, and urban or agricultural runoffs often contain significant "total" nutrient load. Total nutrient includes the organic complexes in both particulate and soluble forms. Except for precise investigations into the activities and biological assimilation of the various forms of nutrients, it is generally sufficient from an ecological perspective to measure total kjeldahl nitrogen, total nitrate plus nitrite nitrogen, and total phosphorus.

Total Kjeldahl Nitrogen includes ammonia and organic nitrogen.

Both are present naturally in surface waters as components of the nitrogen cycle. Ammonia is usually present in very small amounts, and organic nitrogen, in larger amounts, is present as the result of inflow of nitrogenous products from the watershed and from the normal biological life of the stream. Municipal and industrial wastewater, spetic tanks, and feedlot discharges are sources of organic nitrogen in water.

Nitrate plus Nitrite Nitrogen is considered as the inorganic components of the nitrogen cycle present in water. Nitrate is the end product of aerobic decomposition of organic nitrogen, and nitrite is an intermediate product of this process. Since nitrite concentrations are generally low in surface waters, the combined measurement of nitrate and nitrite using the cadmium reduction technique can be reported as a single parameter. Municipal and industrial wastewater, septic tanks, and agricultural or feedlot discharges may be indirect sources of these forms of nitrogen (after oxidation).

Phosphorus is often considered the most critical single factor in maintenance of the biogeochemical cycle in the ecosystem. It is one of the major nutrients required for plant nutrition. Phosphorus is known to occur in several forms, and those of greater concern in the water environment are the soluble inorganic phosphate phosphorus, soluble organic phosphorus, and particulate organic phosphorus. It is generally sufficient to report these forms as total phosphorus from analyzing an unfiltered sample.

Both organic and inorganic phosphorus in water may result from leaching of soils and rock, from fertilizers, from normal decomposition of plants and animals, and from sewage and industrial effluents. When present in excess concentrations, phosphorus stimulates nuisance algal growth in the aquatic environment.

TOTAL NONFILTRABLE RESIDUE (Suspended Solids)

Total nonfiltrable residue is the equivalent terminology currently used for suspended solids by Standard Methods. It is an important parameter to measure the contribution of solid material to the ecosystem. This usually includes both organic and inorganic materials.

Among the detrimental effects of nonfiltrable residue in water are impaired light penetration which decreases the amount of plant growth; and infilling of stream beds and rock spaces, thus depriving animals of their habitat. The nonfiltrable residue can be abrasive, and injure gills and other organs of aquatic animals.

The sorption of chemicals by suspended materials is also important in the aquatic environment. It can lead to a buildup of toxic substances, and upon settling and subsequent releases, the sorbed toxicants may be concentrated at a higher than tolerable level for aquatic organisms.

Nonfiltrable residue concentrations are highest during intense runoff periods, and are considered one of Hawaii's major nonpoint source pollution problems for all receiving waters.

TURBIDITY

Turbidity in water is caused principally by fine sediments such as clay and silt, and by minute organisms and plants that are held in suspension and do not rapidly settle out. Turbidity is an optical property of water, and like nonfiltrable residue, it is highest during periods of heavy runoffs.

Turbid water interferes with recreational and esthetic enjoyment of water. For water supply uses, turbid water interferes with the effectiveness of chlorine disinfection.

FECAL COLIFORM

Bacteria plays an important role in the ecology of streams. Certain bacteria which inhabit the intestines of animals are present in their feces. If these bacteria are present in appreciable numbers in water, the water is considered to have a disease-producing potential. Bacteriological indicators have long been used to determine or indicate the safety of water for drinking and swimming. The total coliform indicator, though widely used for sanitation considerations, is least informative of fecal contamination in natural waters. The fecal coliform bacteria, which comprise a portion of the total coliform group, has proven to be more significant as an indicator of pollution. Fecal coliform bacteria are usually present in the intestinal tract of warm-blooded animals, and their presence in water may indicate recent and possible dangerous contamination.

pH

pH is a measure of acidity or basicity, and is defined as the logarithm of the reciprocal of the hydrogen-ion activity. In natural water, pH is a function of chemical and biological processes. pH has a strong influence on the usability of the water, and it is an essential factor that governs the type of aquatic life in the aquatic ecosystem. For Hawaii's streams, pH values of the water range from less than 5.0 in the headwater regions to greater than 8.0 at the terminal reaches at lower elevations.

DISSOLVED OXYGEN

Dissolved oxygen has always been a major parameter of interest in water quality investigation. It is considered as significant in the protection of aesthetic values of water as well as the maintenance of fish and other aquatic life. Under normal conditions, the dissolved oxygen content in Hawaiian streams is relatively high, tending toward saturation. The introduction of large amounts of organic substance such as sewage or debris from flooding may bring about the lowering of dissolved oxygen content in stream water and other types of fresh waters.

Other factors contributing to varying the level of dissolved oxygen in streams are:

1. Turbulence: Generally increases oxygen content due to aeration of stream.

2. Respiration of Organism: Respiratory activities of plants and animals, and oxidation of organic matter decreases dissolved oxygen in streams.

3. Photosynthesis: Aquatic plants contribute to the oxygen content of water.

4. Temperature and Atmospheric Pressure: The solubility of oxygen varies inversely with temperature and directly with atmospheric pressure.

5. Inflow of Tributaries: The inflow of tributary waters of low oxygen content serves to decrease oxygen content in the receiving streams by dilution.

A daily oxygen rhythm in stream, the diurnal pulse, is largely a reflection of temperature fluctuations and photosynthesis-respiration relationships. The minimum dissolved oxygen level in streams usually occurs prior to the early-morning temperature low.

TEMPERATURE

Temperature of water is an important parameter because of its effect on chemical reactions, as well as physiological or biological metabolism. Stream temperatures in Hawaii do not vary significantly, and they generally fluctuate with ambient conditions. Natural stream temperatures range from 12°-28°C from headwater to terminal reaches. Temperatures of streams are higher flowing in concrete-lined channels and are highest at low-flow conditions.

CONDUCTIVITY

Conductivity is a convenient and rapid determination used to estimate the amount of dissolved solids in water. It is a measure of the ability of water to transmit a small electrical current. Expressed in terms of micromhos per centimeter at 25°C, conductivity is commonly used for fresh water measurements. For the mixohaline and saline waters, salinity determination is preferred. Salinity expresses dissolved solids concentration in terms of parts per thousand.

The conductivity of streams are generally:
less than 50 umhos at the headwater reach;
50-200 umhos at midreach; and
greater than 200 (mainly 100-300) umhos at terminal reach.

JUSTIFICATION FOR MINIMUM STREAM FLOW STANDARDS

Stream dwelling animals require five basic parameters for survival: 1) adequate living space, 2) shelter from predators and torrential flows, 3) abundant food supply, 4) suitable spawning grounds, and 5) a constant physical regime. When living space and shelter are insured the remaining criteria may be naturally provided for. From a standpoint of streamflow, this is basically a function of the extent of the area covered by water. Hence, the amount of suitable habitat available for the support of desirable aquatic resources is directly proportional to the volume of water, or the wetted perimeter, in a stream. Maintenance of continuous streamflow is by far the single most important requirement for the quality of stream waters and the integrity of lotic communities.

In the determination of flow requirements, it is necessary to form an understanding of the tolerances and life requirements of native Hawaiian stream fauna, and species introduced for sport fishery management. Stream discharge must be adequate to induce metamorphosis, settlement and migration, maintain an abundant food supply for all species, and meet their spawning requirements. Water velocity is the dominant physical factor affecting stream life. The Hawaiian stream fauna are well adapted to and require the flow regimens characteristic of relatively small, precipitous streams. Ranges of tolerance may be rather narrow, and often vary with different stages of the life history. Most of the exotic sport fishes cannot tolerate the highly variable flow regime of Hawaiian streams, and therefore may succeed only in reservoirs or in streams where discharge is carefully regulated.

Development, growth, and migration are influenced directly by the current factor. Indirectly, water velocity may determine food and habitat availability through its influence on benthic forms, turbidity, erosion and subsequent sedimentation. The naturally occurring extremes in discharge have adverse affects on stream fauna; however, native stream communities have evolved an elasticity or ability to recover from an acute external stress or disturbance. In relation to fluctuations in streamflow, the most critical ecological factor is the level of discharge during the dry season. During periods of very low flows, habitat area may be drastically reduced; flow velocity through rock interstices reduces the quality of this space for the development of juvenile fishes. During low flows, dissolved oxygen in streams may be depressed and high carbon dioxide tensions may become lethal. Discontinuous flow reduces the habitat to a series of isolated pools which often become stagnant. Flow reduction and stagnation impede the settlement and migration of juvenile animals.

If such a stress is artificially maintained for a period of time (through stream diversion and dewaterment) the ability of the biotic community to recover from the stress is greatly reduced. Where streams are totally dewatered below diversion structures, aquatic fauna may be totally absent - the ecosystem is essentially destroyed for the duration of the induced stress. Curiously, the reproductive biology of the native Hawaiian stream fauna is the key to ecosystem resiliency (the ability to recover biological integrity after a long-term perturbation has been relaxed). Hawaiian freshwater fishes, crustaceans and mollusks possess a diadromous life-cycle: eggs hatch in the stream, larvae develop in the ocean as marine plankton, and juveniles reinvade streams where they grow to maturity. At any one time, coastal waters contain a larval pool of freshwater organisms which may settle and enter streams provided the appropriate environmental cues are present. If stream dewaterment continues, however, breeding populations of these animals will be reduced or destroyed causing subsequent decline in the size of the pelagic larval pool to a point where restoration of stream ecosystems and recovery of desirable species may be severely limited. Today, less than 15% of over 350 perennial stream ecosystems in Hawaii still retain high natural quality.

The proposed minimum streamflow requirements are based upon current research and development of instream flow needs by the U. S. Fish and Wildlife Service. The method used to determine flow standards can be based upon existing U. S. Geological Survey surface water records, and requires a minimum of field studies. It is quick, inexpensive and particularly applicable for streams that have fluctuating flow regimes. This method has proved successful throughout the continental United States.

Rainfall and stream discharge records for the Hawaiian Islands clearly demonstrate a seasonal fluctuation in flow. Thus, Hawaii's two seasons, summer (May 1 through October 31) and winter (November 1 through April 30), have been used to establish seasonal stream flow requirements. Calculation of mean monthly discharge indicates that stream flows are lower in the summer than in the winter. In summer, low stream flows are maintained primarily by groundwater seepage. Since flows are already marginal and natural stresses to the aquatic biota may occur, diversions permissible in the Class III and Class IV use categories (see Appendix 9) must be kept to a minimum to prevent total degradation of the stream ecosystems. During the winter, surface flow is maintained both by abundant rainfall and through groundwater seepage. These higher discharges allow a greater proportion of water to be diverted before ecological stress occurs. Therefore, the minimum stream flow standards for winter can be lower.

Where future stream diversions are to be permitted, a 10% never-to-exceed requirement has been established and represents the absolute minimum discharge allowable before severe degradation to the stream ecosystems may be expected to occur. Channel widths, depths, and velocities will all be significantly reduced and aquatic habitat degraded. The wetted perimeter will be about half exposed, and the side channels will be severely to completely dewatered. Many wetted areas will be so shallow they no longer will serve as cover. Riparian vegetation may suffer from lack of water, and higher water temperatures may become a limiting factor. Natural beauty and stream aesthetics are badly degraded.

A 30% base flow for winter months is recommended to sustain survival habitat for most aquatic life forms. The majority of the substrate will be covered with water, and most side channels will carry some water. Streambanks will provide cover for fish and wildlife, and riparian vegetation will not suffer from lack of water. Water temperatures are not expected to become limiting; and water quality and quantity should be sufficient for recreational fishing and general recreation.

The 50% base flow during the summer is necessary to prevent excessive degradation of stream ecosystems which are naturally stressed by low flows. Physical nature of the stream substrata and discharge will be similar in nature to the 30% base flow.

All minimum streamflow standards have been set for discharge volume at the mouth of streams where flow is critical to biological needs.

PROPOSED WATER QUALITY SAMPLING SCHEME

The following table outlines a proposed scheme for water quality sampling of inland waters. A three year sampling program is recommended to gather data to refine the proposed standards as well as to expand the proposed standards to include other inland water subtypes.

The suggested frequency of sampling are:
- monthly for streams and estuaries;
- quarterly for low wetlands and coastal wetlands; and
- semi-annually for all others.

Semi-annual sampling should be made to coincide with the wet and dry seasons.

It is not practical nor necessary to sample every inland water body. Each subtype should be examined for similarity in geological, physical and hydrological features in order that representative sampling can be done at as few sites as practical. The sampling should include areas of known water quality problems (e.g., water quality segment designated areas) as well as pristine areas where problems are not expected.

After baseline conditions and natural variability have been established, it may not be necessary to continue the frequency of sampling in the pristine water bodies.

PROPOSED WATER QUALITY SAMPLING SCHEME
INLAND WATERS

	FRESHWATER							MIXOHALINE AND SALINE		
PARAMETER	STREAMS	DITCH & FLUMES	SPRINGS & SEEPS	NATURAL LAKES	RESER-VOIRS	ELEVATED WETLANDS	LOW WETLANDS	COASTAL WETLANDS	ESTU-ARIES	ANCHIA-LINE POOLS
Total KJD-N	M	SA	SA	SA	SA	SA	Q	Q	M	SA
$NO_3 + NO_2$ -N	M	SA	SA	SA	SA	SA	Q	Q	M	SA
Total Phosphorus	M	SA	SA	SA	SA	SA	Q	Q	M	SA
Nonfiltrable Residue	M	SA	SA	SA	SA	SA	Q	Q	M	SA
Turbidity	M	SA	SA	SA	SA	SA	Q	Q	M	SA
Fecal Coliform	M	SA	SA	SA	SA	SA	Q	Q	M	SA
pH	M	SA	SA	SA	SA	SA	Q	Q	M	SA
Dissolved Oxygen	M	SA	SA	SA	SA	SA	Q	Q	M	SA
Temperature	M	SA	SA	SA	SA	SA	Q	Q	M	SA
Conductivity/Salinity	M	SA	SA	SA	SA	SA	Q	Q	M	SA

M = Monthly; Q = Quarterly; SA = Semi-annual

APPENDIX 5

CRITERIA FOR MINIMUM STREAM FLOW STANDARDS

Introduction

Streams represent Hawaii's most abundant inland water type by area and volume, and are intimately tied to land and sea through the hydrologic cycle. A stream and its watershed are as inseparable in concept as the ocean and the shore. In their natural state, streams serve numerous vital ecological functions including habitat for rare and endangered aquatic species and waterfowl, habitat for both native and introduced fishery resources, a pathway for the introduction of nutrients into estuarine and coastal marine environments, and an essential link with groundwater supplies and aquifers. Streams also provide a pathway of dilution and transport for man-created pollutants.

Stream quality has been severely degraded in Hawaii by two primary types of hydrologic modification: dewaterment and channel alteration. Less than 15% of over 350 perennial stream ecosystems still retain high natural quality.

Recognizing that maintenance of its natural streams' environmental integrity is of premier importance, the State of Hawaii, Department of Health, is proposing the establishment of minimum stream flow standards. The objectives of these standards involves the protection of pristine habitats, conservation of fishery resources through restoration of degraded habitat, conservation of recreational opportunities, conservation of aesthetic/scenic resources, and regulation of stream dewaterment for more careful management of Hawaii's freshwater resources.

Criteria

All perennial streams will be categorized and subject to the requirements set forth for their respective use category. Compliance with the minimum stream flow requirements does not exempt one from complying with water quality standards. In certain cases, water quality standards may be violated before stream flow requirements are violated, and vice versa. Similarly, violations of water quality standards may directly result from stream flow reduction.

Ditches and flumes are exempted from categorization since they are not considered to be natural stream ecosystems.

The criteria and standards proposed herein are based upon current research and development of minimum flow requirements by the U. S. Fish and Wildlife Service (Tennant, 1976; Stalnaker and Arnette, 1976). The method used to determine flow standards can be based upon existing U. S. Geological Survey surface water records, and requires a minimum of field studies. It is quick, inexpensive, and particularly applicable for streams that have fluctuating flow regimes, as Hawaii's streams have. This method has proved successful statewide.

Rainfall and stream discharge records for the Hawaiian Islands clearly demonstrate a seasonal fluctuation in flow regimes. Thus, Hawaii's two seasons, summer (May 1 through October 31) and winter (November 1 through April 30), have been used to establish seasonal stream flow requirements. Calculation of mean monthly discharge indicates that stream flows are lower in the summer than in the winter.

In summer, low stream flows are maintained primarily by groundwater seepage. Since flows are already marginal and natural stresses to the aquatic biota may occur, diversions permissible in the Class III and Class IV use categories (see Appendix 9 for Use Classification and Descriptions) must be kept to a minimum to prevent total degradation of the stream ecosystems. During the winter, surface flow is maintained both by abundant rainfall and through groundwater seepage. These higher discharges allow a greater proportion of water to be diverted before ecological stress occurs. Therefore, the minimum stream flow standards for winter can be lower.

The 10% never-to-exceed requirement is the absolute minimum discharge allowable before severe degradation to the stream ecosystem may be expected to occur. Channel widths, depths, and velocities will all be significantly reduced and aquatic habitat degraded. The stream substrate or wetted perimeter will be about half exposed, and the side channels will be severely to totally dewatered. Many wetted areas will be so shallow they no longer will serve as cover. Riparian vegetation may suffer from lack of water, and higher water temperatures may become a limiting factor. Natural beauty and stream aesthetics are badly degraded.

The 30% base flow during the winter months is recommended to sustain survival habitat for most aquatic life forms. The majority of the substrate will be covered with water, and most side channels will carry some water. Streambanks will provide cover for fish and wildlife, and riparian vegetation will not suffer from lack of water. Water temperatures are not expected to become limiting; and water quality and quantity should be sufficient for recreational fishing and general recreation.

The 50% base flow during the summer is necessary to prevent excessive degradation of stream ecosystems which are naturally stressed by low flows. Physical nature of the stream substrata and discharge will be similar in nature to the 30% base flow.

Minimum Stream Flow Standards

The following minimum stream flow standards for perennial streams have been established according to stream use.

I. Pristine-Preservation

Function: To preserve naturally existing stream ecology and natural means of groundwater recharge.

Qualifications: Any partly diverted or undiverted stream which must retain optimal flow in order to ensure the preservation of its ecology; those sections of streams which flow through designated watersheds up to and including headwaters.

Standard: No further diversion or other unnatural causes of stream flow reduction (including groundwater use) shall be permitted.

II. Limited Consumptive

Function: To relieve streams of ecological stress caused by stream flow reduction; preservation of habitat for fishery resources.

Qualifications: Any diverted stream suffering ecological stress due to flow reduction which has the potential of recovering from that stress, providing that stream flow is not reduced further.

Standard: No further diversions shall be permitted; reduce the amount of water being diverted in order to meet the minimum stream flow requirement set to allow a particular stream to recover from ecological stress, where specified by the Director.

III. Exploitive Consumptive

Function: To regulate stream diversions

Qualifications: Any stream which does not qualify in the first two use categories. Minimum stream flow standards shall apply to all stream diversions completed after adoption of the standards.

Criteria:

1. From May 1 through October 31, instantaneous discharge at the stream mouth* shall not be reduced by unnatural causes, to less than fifty percent (50%) of its <u>lowest instantaneous flow</u> for the same period.
2. From November 1 through April 30, instantaneous discharge at the stream mouth* shall not be reduced, by unnatural causes, to less than thirty percent (30%) of its <u>lowest instantaneous flow</u> for the same period.
3. At any moment during the year, instantaneous stream flow at any point along the stream course (excluding the mouth) shall not be reduced, by unnatural causes, to less than ten percent (10%) of its <u>lowest instantaneous flow</u>.

*The stream mouth shall be defined as the lowest reach along the stream course where there is no mixing of fresh and saline waters, or just above the head of the estuarine basin.

These standards are set for discharge at the mouth of streams where flow is critical to biological needs.

IV. References

1. Stalnaker, C. B. and J. L. Arnette. 1976. Methodologies for determining instream flow needs for fish and other aquatic life. (In): Methodologies for the determination of stream resource flow requirements: an assessment. USFWS-OBS, Logan, Utah.

2. Tennant, D. L. 1976. Instream flow regimens for fish, wildlife, recreation, and related environmental resources. Fisheries 1(4):6-10.

APPENDIX 6

STANDARDS FOR TOXIC SUBSTANCES IN FRESHWATERS

METALS

Parameter	Standard
Arsenic (ug/l)	less than 50 ug/l
Cadmium (ug/l)	less than 0.4 ug/l (soft fresh water) less than 1.2 ug/l (hard fresh water)
Chromium (ug/l)	less than 100 ug/l
Copper	*less than 0.1 times the 96-hour LC50 value
Cyanide (ug/l)	less than 5 ug/l
Lead	*less than 0.01 times the 96-hour LC50 value
Manganese (ug/l)	less than 50 ug/l
Mercury (ug/l)	less than 0.05 ug/l
Nickel	*less than 0.01 times the 96-hour LC50 value
Selenium	*less than 0.01 times the 96-hour LC50 value
Silver	*less than 0.01 times the 96-hour LC50 value
Zinc	*less than 0.01 times the 96-hour LC50 value

Note: *Value determined through bioassay using a sensitive resident species.

OIL

Parameter	Standard
Oil and other petroleum products	No oil or petroleum products shall be discharged into inland waters that: -can be detected as a visible film, sheen, or discoloration of the surface, or by odor -can cause tainting of fish or invertebrates or other biological damage

-can form an oil deposit on the banks or bottom of the water body

PESTICIDES AND OTHER ORGANICS

Parameter	Standard
Aldrin (ug/l)	less than 0.003 ug/l
Dieldrin (ug/l)	less than 0.003 ug/l
Chlordane (ug/l)	less than 0.01 ug/l
DDT (ug/l)	less than 0.001 ug/l
Demeton (ug/l)	less than 0.1 ug/l
Endosulfan (ug/l)	less than 0.003 ug/l
Endrin (ug/l)	less than 0.004 ug/l
Guthion (ug/l)	less than 0.01 ug/l
Heptachlor (ug/l)	less than 0.001 ug/l
Lindane (ug/l)	less than 0.01 ug/l
Malathion (ug/l)	less than 0.1 ug/l
Methoxychlor (ug/l)	less than 0.03 ug/l
Mirex (ug/l)	less than 0.001 ug/l
Parathion (ug/l)	less than 0.04 ug/l
Toxaphene (ug/l)	less than 0.005 ug/l
Phthalate Esters (ug/l)	less than 3 ug/l
Phenol (ug/l)	less than 1 ug/l
Polychlorinated Biphenyls (ug/l)	less than 0.001 ug/l

RADIONUCLIDES

Parameter	Standard
Radionuclides	Aquatic organisms concentrate radioisotopes to various degrees in their tissues. The concentration in inland waters should be low enough so that the concentration in any aquatic species will not exceed Radiation Protection Guides of the U. S. Federal Radiation Council (1961) for organisms harvested for use as human food. This recommendation is based upon the assumption that radiation levels which are acceptable as human food will not injure the aquatic organisms including wildlife.

Reference: Quality Criteria For Water, U. S. Environmental Protection Agency.

APPENDIX 7

.ANDARDS FOR TOXIC SUBSTANCES IN MARINE WATERS

.rameter	Standard
Arsenic (ug/l)	less than 10 ug/l
Cadmium (ug/l)	less than 5.0 ug/l
Chromium (ug/l)	less than 100 ug/l
Copper	*less than 0.1 times the 96-hour LC50 value
Cyanide (ug/l)	less than 5.0 ug/l
Lead	*less than 0.1 times the 96-hour LC50 value
Manganese (ug/l)	less than 100 ug/l
Mercury (ug/l)	less than 0.2 ug/l
Nickel	*less than 0.01 times the 96-hour LC50 value
Selenium	*less than 0.01 times the 96-hour LC50 value
Silver	*less than 0.01 times the 96-hour LC50 value
Zinc	*less than 0.01 times the 96-hour LC50 value

Note: *Value determined through bioassay using a sensitive resident species.

OIL

Parameter	Standard
Oil and other petroleum products	No oil or petroleum products shall be discharged into marine waters that: -can be detected as a visible film, sheen or discoloration of the surface, or by odor; -can cause tainting of fish or invertebrates or other biological damage

-can form an oil deposit on the banks
or bottom of the water body

PESTICIDES AND OTHER ORGANICS

Parameter	Standard
Aldrin (ug/l)	less than 0.003 ug/l
Dieldrin (ug/l)	less than 0.003 ug/l
Chlordane (ug/l)	less than 0.004 ug/l
DDT (ug/l)	less than 0.001 ug/l
Demeton (ug/l)	less than 0.1 ug/l
Endosulfan (ug/l)	less than 0.001 ug/l
Endrin (ug/l)	less than 0.004 ug/l
Guthion (ug/l)	less than 0.01 ug/l
Heptachlor (ug/l)	less than 0.001 ug/l
Lindane (ug/l)	less than 0.004 ug/l
Malathion (ug/l)	less than 0.1 ug/l
Methoxychlor (ug/l)	less than 0.03 ug/l
Mirex (ug/l)	less than 0.001 ug/l
Parathion (ug/l)	less than 0.04 ug/l
Toxaphene (ug/l)	less than 0.005 ug/l
Phenol (ug/l)	less than 200 ug/l
Phthalate Esters (ug/l)	less than 3 ug/l
Polychlorinated Biphenyls (ug/l)	less than 0.001 ug/l

RADIONUCLIDES

Parameter	Standard
Radionuclides	Aquatic organisms concentrate radioisotopes to various degrees in their tissues. The concentration in sea water should be low enough so that the concentration in any aquatic species will not exceed Radiation Protection Guides of the U. S. Federal Radiation Council (1961) for organisms harvested for use as human food. This recommendation is based upon the assumption that radiation levels which are acceptable as human food will not injure the aquatic organisms including wildlife.

Reference: Quality Criteria For Water, U. S. Environmental Protection Agency.

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APPENDIX 8

Use Levels:
Inland Water Ecosystems

Five status-use categories are designated for classifying inland water ecosystems with regard to applying water quality standards and selecting or defining appropriate quality parameters. All categories except No. 1 apply to both natural and artificial ecosystems.

I.a. Pristine-Preservation: Public access allowed

Applicable only to natural ecosystems and relevant only to those of high to very high environmental and biological quality. Preservation status in accord with objectives of Hawaii Natural Area Reserves System Commission for total ecosystem preservation. Intent is to recognize and perpetuate intrinsic values for scientific and educational purposes, genetic pools and baseline references from which degrees of man-induced changes can be measured. Public access but no consumptive or otherwise degrading or modifying uses permissible.

I.b. Pristine-Preservation: Public access restricted

High natural quality and/or high water quality for special exploitive (but non-degrading) use. May be restricted to public access. Domestic water supplies and some natural area reserves (for designated features only).

II. Limited Consumptive

Moderate to high quality water or natural values that may be partially degraded through use which is controlled to prevent excessive modification. Uses include recreational fishing, swimming and aquaculture water supply.

III. Exploitive Consumptive

Moderate to low natural and/or water quality; well exploited, modified or degraded but usable for recreational and some body contact purposes (boating, water skiing, fishing, etc.).

IV. Construct/Alter

Low quality water, aesthetics and ecological features. Mainly effluent or receiving waters whose quality cannot be raised and which may be restricted to the public for health or safety reasons.

APPENDIX 9

Use Levels:
Marine Water Ecosystems

I. Pristine-Preservation

Passive human use without intervention or alteration, allowing the perpetuation and preservation of waters in a most natural state. Examples: non-consumptive scientific research (demonstration, observation and/or monitoring only), non-consumptive education, aesthetic enjoyment and inactive management/preservation.

II. Limited Consumptive

Passive to active human use which alters the character or properties of the water without significant degradation, allowing perpetual use at the same level. Examples: scientific research (all types), whole and limited body contact recreation and recreational or subsistence fishing and hunting.

III. Exploitive Consumptive

Active human use which significantly degrades the quality or properties of the water. Examples: receiving waters for treated wastewater and thermal discharges (municipal, agricultural or industrial), hydroelectric power, food processing, heavy commercial/industrial fishing and water degrading agriculture.

IV. Construct/Alter

Active human use which permanently or completely modifies, consumes, degrades or commits waters. Examples: structural flood control (channelization, dams), hydroelectric power plants, landfill and reclamation, structural navigation (harbors, ramps), structural shore protection (seawalls, revetments) and wastewater effluents.